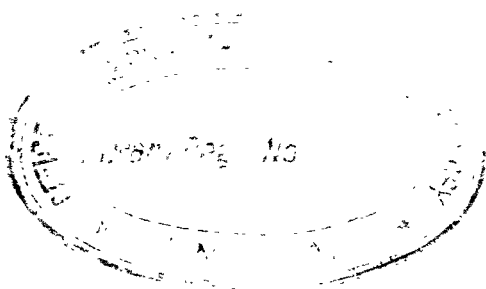ANNUAL REPORT OF THE
BOARD OF REGENTS OF

THE SMITHSONIAN
INSTITUTION

SHOWING THE

OPERATIONS, EXPENDITURES, AND
CONDITION OF THE INSTITUTION
FOR THE YEAR ENDING JUNE 30

19.13

4

LETTER

SECRETARY OF THE SMITHSONIAN INSTITUTION,

THE ANNUAL REPORT OF THE BOARD OF REGENTS OF THE INSTITUTION FOR THE YEAR ENDING JUNE 30, 1913.

———————————

SMITHSONIAN INSTITUTION,
Washington, May 15, 1914.

To the Congress of the United States:

In accordance with section 5593 of the Revised Statutes of the United States, I have the honor, in behalf of the Board of Regents, to submit to Congress the annual report of the operations, expenditures, and condition of the Smithsonian Institution for the year ending June 30, 1913. I have the honor to be.

Very respectfully, your obedient servant,

CHARLES D. WALCOTT, *Secretary.*

CONTENTS.

LIST OF PLATES.

ANNUAL REPORT OF THE BOARD OF REGENTS OF THE SMITHSONIAN INSTITUTION FOR THE YEAR ENDING JUNE 30, 1913.

SUBJECTS.

1. Annual report of the secretary, giving an account of the operations and conditions of the Institution for the year ending June 30, 1913, with statistics of exchanges, etc.

2. Report of the executive committee, exhibiting the financial affairs of the Institution, including a statement of the Smithsonian fund, and receipts and expenditures for the year ending June 30, 1913.

3. Proceedings of the Board of Regents for the sessions of December 12, 1912, and February 13, 1913.

4. General appendix, comprising a selection of miscellaneous memoirs of interest to collaborators and correspondents of the Institution, teachers, and others engaged in the promotion of knowledge. These memoirs relate chiefly to the calendar year 1913.

THE SMITHSONIAN INSTITUTION

June 30, 1913.

Presiding officer ex officio.—WOODROW WILSON, President of the United States.
Chancellor.—EDWARD DOUGLASS WHITE, Chief Justice of the United States.
Members of the Institution:
    WOODROW WILSON, President of the United States.
    THOMAS R. MARSHALL, Vice President of the United States.
    EDWARD DOUGLASS WHITE, Chief Justice of the United States.
    WILLIAM JENNINGS BRYAN, Secretary of State.
    WILLIAM GIBBS McADOO, Secretary of the Treasury.
    LINDLEY MILLER GARRISON, Secretary of War.
    JAMES CLARK McREYNOLDS, Attorney General.
    ALBERT SIDNEY BURLESON, Postmaster General.
    JOSEPHUS DANIELS, Secretary of the Navy.
    FRANKLIN KNIGHT LANE, Secretary of the Interior.
    DAVID FRANKLIN HOUSTON, Secretary of Agriculture.
    WILLIAM COX REDFIELD, Secretary of Commerce
    WILLIAM BAUCHOP WILSON, Secretary of Labor.
Regents of the Institution:
    EDWARD D. WHITE, Chief Justice of the United States, Chancellor.
    THOMAS R. MARSHALL, Vice President of the United States.
    HENRY CABOT LODGE, Member of the Senate.
    AUGUSTUS O. BACON, Member of the Senate.
    WILLIAM J. STONE, Member of the Senate.
    JOHN DALZELL, Member of the House of Representatives.
    SCOTT FERRIS, Member of the House of Representatives.
    IRVIN S. PEPPER, Member of the House of Representatives.
    ANDREW D. WHITE, citizen of New York.
    ALEXANDER GRAHAM BELL, citizen of Washington, D. C.
    GEORGE GRAY, citizen of Delaware.
    CHARLES F. CHOATE, Jr., citizen of Massachusetts.
    JOHN B. HENDERSON, Jr., citizen of Washington, D. C.
    CHARLES W. FAIRBANKS, citizen of Indiana.
Executive committee.—A. O. BACON, ALEXANDER GRAHAM BELL, JOHN DALZELL.
Secretary of the Institution.—CHARLES D. WALCOTT.
Assistant secretary in charge of the National Museum.—RICHARD RATHBUN.
Assistant secretary in charge of Library and Exchanges.—FREDERICK W. TRUE.
Chief clerk.—HARRY W. DORSEY.
Accountant and disbursing agent.—W. I. ADAMS.
Editor.—A. HOWARD CLARK.
Assistant librarian.—PAUL BROCKETT.
Property clerk.—J. H. HILL.

THE NATIONAL MUSEUM.

Keeper ex officio.—CHARLES D. WALCOTT, Secretary of the Smithsonian Institution.
Assistant secretary in charge.—RICHARD RATHBUN.
Administrative assistant.—W. DE C. RAVENEL.
Head curators.—WILLIAM H. HOLMES, LEONHARD STEJNEGER, G. P. MERRILL,
Curators.—R. S. BASSLER, A. HOWARD CLARK, F. W. CLARKE, F. V. COVILLE,
W. H. DALL, B. W. EVERMANN, CHESTER G. GILBERT, W. H. HOLMES, WALTER
HOUGH, L. O. HOWARD, ALEŠ HRDLIČKA, FREDERICK L. LEWTON, GEORGE C.
MAYNARD, G. P. MERRILL, GERRIT S. MILLER, Jr., RICHARD RATHBUN, ROBERT
RIDGWAY, LEONHARD STEJNEGER, CHARLES D. WALCOTT.
Associate curators.—J. C. CRAWFORD, DAVID WHITE.
Curator, National Gallery of Art.—W. H. HOLMES.
Chief of correspondence and documents.—RANDOLPH I. GEARE.
Disbursing agent.—W. I. ADAMS.
Chief of exhibits (Biology).—JAMES E. BENEDICT.
Superintendent of construction and labor.—J. S. GOLDSMITH.
Editor.—MARCUS BENJAMIN.
Assistant librarian.—N. P. SCUDDER.
Photographer.—T. W. SMILLIE.
Registrar.—S. C. BROWN.
Property clerk.—W. A. KNOWLES.
Engineer.—C. R. DENMARK.

BUREAU OF AMERICAN ETHNOLOGY.

Ethnologist in charge.—F. W. HODGE.
Ethnologists.—J. WALTER FEWKES, J. N. B. HEWITT, F. W. HODGE, FRANCIS
LA FLESCHE, TRUMAN MICHELSON, JAMES MOONEY, MATILDA COXE STEVENSON,
JOHN R. SWANTON.
Special ethnologist.—LEO J. FRACHTENBERG.
Honorary philologist.—FRANZ BOAS.
Editor.—JOSEPH G. GURLEY.
Librarian.—ELLA LEARY.
Illustrator.—DE LANCEY GILL.

INTERNATIONAL EXCHANGES.

Assistant secretary in charge.—FREDERICK W. TRUE.
Chief clerk.—C. W. SHOEMAKER.

NATIONAL ZOOLOGICAL PARK.

Superintendent.—FRANK BAKER.
Assistant superintendent.—A. B. BAKER.

ASTROPHYSICAL OBSERVATORY.

Director.—C. G. ABBOT.
Aid.—F. E. FOWLE, Jr.
Bolometric assistant.—L. B. ALDRICH.

REGIONAL BUREAU FOR THE UNITED STATES, INTERNATIONAL CATALOGUE OF SCIENTIFIC LITERATURE.

Assistant in charge.—LEONARD C. GUNNELL.

REPORT

OF THE

SECRETARY OF THE SMITHSONIAN INSTITUTION

CHARLES D. WALCOTT

FOR THE YEAR ENDING JUNE 30, 1913.

To the Board of Regents of the Smithsonian Institution:

GENTLEMEN: I have the honor to submit herewith a report on the operations of the Smithsonian Institution and its branches during the fiscal year ending June 30, 1913, including work placed by Congress under the direction of the Board of Regents in the United States National Museum, the Bureau of American Ethnology, the International Exchanges, the National Zoological Park, the Astrophysical Observatory, and the United States Bureau of the International Catalogue of Scientific Literature. There is also included an outline of work proposed in the Langley Aerodynamical Laboratory, the establishment of which has been authorized by the Board of Regents under a grant from the Hodgkins fund of the Institution.

The general report reviews the affairs of the Institution proper and briefly summarizes the operations of its several branches, while the appendices contain detailed reports by the assistant secretaries and others directly in charge of various activities. The reports on operations of the National Museum and the Bureau of American Ethnology will also be published as independent volumes.

THE SMITHSONIAN INSTITUTION.

THE ESTABLISHMENT.

The Smithsonian Institution was created an establishment by act of Congress approved August 10, 1846. Its statutory members are the President of the United States, the Vice President, the Chief Justice, and the heads of the executive departments.

THE BOARD OF REGENTS.

The Board of Regents consists of the Vice President and the Chief Justice of the United States as ex officio members, three members of the Senate, three Members of the House of Representatives, and six citizens, "two of whom shall be resident in the city

of Washington, and the other four shall be inhabitants of some State, but no two of them of the same State."

In regard to the personnel of the board it becomes my sad duty to record the death on October 30, 1912, of its Chancellor, James Schoolcraft Sherman, Vice President of the United States. Resolutions in memory of Chancellor Sherman were adopted by the Regents at their annual meeting on December 12, when the Hon. Edward D. White, Chief Justice of the United States, was elected Chancellor of the Institution.

Dr. Andrew D. White was reappointed as Regent to serve until June 26, 1918; the Hon. Charles W. Fairbanks to serve until July 3, 1918; and Judge Gray to serve until February 7, 1919. Senator Bacon was reappointed a Regent, and Senator William J. Stone was appointed to succeed the Hon. Shelby M. Cullom, whose term as United States Senator expired in March, 1913. The Hon. Thomas R. Marshall, Vice President of the United States, became a Regent on March 4, 1913.

The roll of Regents at the close of the fiscal year was as follows: Edward D. White, Chief Justice of the United States, Chancellor; Thomas R. Marshall, Vice President of the United States; Henry Cabot Lodge, Member of the Senate; Augustus O. Bacon, Member of the Senate; William J. Stone, Member of the Senate; John Dalzell, Member of the House of Representatives; Scott Ferris, Member of the House of Representatives; Irvin S. Pepper, Member of the House of Representatives; Andrew D. White, citizen of New York; Alexander Graham Bell, citizen of Washington, D. C.; George Gray, citizen of Delaware; Charles F. Choate, jr., citizen of Massachusetts; John B. Henderson, jr., citizen of Washington, D. C.; and Charles W. Fairbanks, citizen of Indiana.

Regular meetings of the Board of Regents were held on December 12, 1912, and February 13, 1913, and a special meeting on May 1, 1913. The minutes of these meetings have been printed as usual for the use of the Regents, while such important matters acted upon as are of public interest are reviewed under appropriate heads in the present report of the secretary. The annual financial report of the Executive Committee has also been issued in the usual form, and a detailed statement of disbursements from Government appropriations under the direction of the Institution for the maintenance of the National Museum, the National Zoological Park, and other branches will be submitted by the secretary to Congress in compliance with the law.

GENERAL CONSIDERATIONS.

The activities of the Smithsonian Institution under its plan of organization cover practically the entire field of the natural and physical sciences, as well as anthropological and archeological re-

searches. The Institution was founded for the increase and diffusion of knowledge. It is an Institution of record, research, and education, and also of cooperation. It offers facilities for the advancement of human knowledge through original research and investigation in every field and educates the people through the publication of the results of such researches. There is reciprocal cooperation between the Smithsonian Institution and the several departments of the United States Government and learned societies in this country and abroad in carrying forward important explorations and lines of investigation.

Some of the scientific studies originating with the Smithsonian Institution in this country have since developed into distinct and important bureaus and departments of the Government. The influence of the Institution is world-wide; through its international exchange service alone it is in correspondence with more than 60,000 individuals and learned societies in the United States and practically in every land on the globe. During its entire existence there has been an unbroken record of friendly intercourse with every agency devoted to the encouragement of learning. As was said in 1896, by the late Dr. Daniel Coit Gilman, " Without any patronage, without the power to bestow much pecuniary assistance, * * * the Smithsonian has been, and is, the great auxiliary of science and education throughout the length and breadth of the land."

The extent of the activities of the Institution is limited only by the amount of the funds available. During recent years its private income has been supplemented on several occasions by friends of the Institution who have generously provided the means for carrying on certain explorations and lines of research, but opportunities for further important work constantly arise which must be declined or temporarily held in abeyance. Some of the projects proposed are such as could not properly be carried on through Government appropriation, but which the Smithsonian Institution could readily undertake were the means available.

Research Corporation.—The work of the Research Corporation, organized primarily for handling the Cottrell patents offered to the Institution for the benefit of research, has been progressing steadily during the year. As explained in detail in my last report, this corporation was organized February 8, 1912, under the laws of the State of New York as a means of furthering scientific and technical research. It objects as stated in its prospectus are:

First, to acquire inventions and patents and to make them more available in the arts and industries, while using them as a source of income, and, second, to apply all profits derived from such use to the advancement of technical and scientific investigation and experimentation through the agency of the Smithsonian Institution and such other scientific and educational institutions and societies as may be selected by the directors. For these purposes the corpora-

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tion has been capitalized at $20,000, divided into 200 shares, but the charter provides that no dividends shall be paid and that the entire net profits shall be devoted to research, all the stock being held under a stockholders' agreement, which recites that the corporation has been organized for the purpose of aiding and encouraging technical and scientific research, and not for personal or individual profit.

At the present time many discoveries are constantly being made, which undoubtedly possess a greater or less potential value, but which are literally being allowed to go to waste for lack of thorough development. This is due, in some cases, to the fact that the inventors are men in the service of the Government or in the universities or technical schools, who are retarded either by official positions, lack of means, or reluctance to engage in commercial enterprises, and in other cases to the fact that a discovery made incidentally in the laboratory of a manufacturing corporation does not lend itself to the particular purpose of such corporation. True conservation demands that such by-products as these shall be developed and utilized to the fullest extent of which they are capable. The Research Corporation aims to supply this demand and, through the cooperation of the Smithsonian Institution and the universities, to carry forward the work of investigation already begun by others upon lines which promise important results and to perfect such inventions as may prove to possess commercial value, thus bringing scientific institutions into closer relations with industrial activities and furthering the improvements of industrial processes.

The establishment of the Research Corporation was rendered immediately possible by the acquisition, through the gift of Dr. F. G. Cottrell, of the United States Bureau of Mines, and his associates, of a valuable set of patents relating to the precipitation of dust, smoke, and chemical fumes by the use of electrical currents. These devices are in operation in several States, and are fully described in an article in Industrial and Engineering Chemistry, for August, 1911.

A number of other patents in various fields of industry have been offered by officers of the Government and scientific institutions, as well as by manufacturing corporations holding patents not available for their own purposes, and undoubtedly there are many others, both in this country and abroad, who will be glad to have their inventions utilized for the benefit of scientific research. The Smithsonian Institution is interested in the management of this corporation through the membership of the secretary in its board of directors, which is composed of business and professional men, many of whom have had experience in large industrial and mining enterprises.

The George W. Poore bequest.—By the terms of the will of the late George W. Poore, of Lowell, Mass., who died December 17, 1910, the Smithsonian Institution becomes his residuary legatee. As mentioned in my 1910 report, the estate, estimated at about $40,000, is bequeathed under the condition that the income of this sum should be added to the principal until a total of $250,000 should have been reached, and that then the income only should be used for the purposes for which the Institution was created. The estate is still in process of settlement by the executors.

As a reason for making this bequest to the Smithsonian Institution, Mr. Poore in his will says: " I make this gift not so much because of its amount as because I hope it will prove an example for other Americans to follow, by supporting and encouraging so wise and beneficent an institution as I believe the Smithsonian Institution to be, and yet it has been neglected and overlooked by American citizens."

The Kahn Foundation.—The Smithsonian Institution is closely allied with a number of organizations and movements of importance to the public through the membership of the secretary in various boards of trustees. Some of these are mentioned elsewhere in this report and among others are the Carnegie Institution of Washington, with whose administration the secretary has been connected since its establishment, and " The Kahn Foundation for the Foreign Travel of American Teachers." The last-named organization was founded in 1911 through a deed of gift and trust between Albert Kahn, of Paris, France, of the first part, and Edward D. Adams, Nicholas Murray Butler, Henry Fairfield Osborn, of New York; Charles W. Eliot, of Cambridge; and Charles D. Walcott, of Washington, of the second part. The founder had heretofore established certain trust funds in France, Germany, Japan, England, and other countries for the purpose of defraying the expenses of teachers and supplying them with what he termed " bourses de voyage " so as to enable them to travel, observe, and study in foreign countries. He believes " that the cause of civilization may be greatly encouraged and promoted by travel on the part of teachers, scholars, and investigators, and that, by the study and comparison of national manners and customs, and of political, social, religious, and economic institutions of foreign countries, they will become better qualified to teach and to take part in the instruction and education of the people of their own nation." In the selection of beneficiaries of the Kahn Foundation preference is given to professors of American colleges or universities and, as a rule, the itinerary is expected to involve an absence from America of at least a year. The limited size of the fund does not permit the granting of more than two or three fellowships each year.

FINANCES.

The permanent fund of the Institution and the sources from which it was derived are as follows:

Deposited in the Treasury of the United States.

Bequest of Smithson, 1846	$515,169.00
Residuary legacy of Smithson, 1867	26,210.63
Deposit from savings of income, 1867	108,620.37
Bequest of James Hamilton, 1875	$1,000
Accumulated interest on Hamilton fund, 1895	1,000
	2,000.00

Bequest of Simeon Habel, 1880	$500.00
Deposits from proceeds of sale of bonds, 1881	51,500.00
Gift of Thomas G. Hodgkins, 1891	200,000.00
Part of residuary legacy of Thomas G. Hodgkins, 1894	8,000.00
Deposit from savings of income, 1903	25,000.00
Residuary legacy of Thomas G. Hodgkins, 1907	7,918.69
Deposit from savings of income, 1913	636.94
Bequest of William Jones Rhees, 1913	251.95
Deposit of proceeds from sale of real estate (gift of Robert Stanton Avery), 1913	9,692.42
Total amount of fund in the United States Treasury	955,500.00

<center>OTHER RESOURCES.</center>

Registered and guaranteed bonds of the West Shore Railroad Co., part of legacy of Thomas G. Hodgkins (par value)	42,000.00
Total permanent fund	997,500.00

There were originally four pieces of real estate bequeathed to the Institution by the late R. S. Avery, but during the year one of these pieces and a part of another were sold and the proceeds added to the permanent fund. The real estate owned by the Institution is free from taxation and yields a nominal rental.

That part of the fund deposited in the Treasury of the United States bears interest at 6 per cent per annum, under the provisions of the act organizing the Institution and an act of Congress approved March 12, 1894. The rate of interest on the West Shore Railroad bonds is 4 per cent per annum.

The income of the Institution during the year, amounting to $92,870.74, was derived as follows: Interest on the permanent foundation, $58,375.12; contributions from various sources for specific purposes, $16,575.50; and from other miscellaneous sources, $17,920.12; all of which was deposited in the Treasury of the United States to the credit of the current account of the Institution.

With the balance of $33,060.09 on July 1, 1912, the total resources for the fiscal year amounted to $125,930.83. The disbursements which are given in detail in the annual report of the executive committee, amounted to $92,289.43, leaving a balance of $33,641.40 on deposit June 30, 1913, in the United States Treasury.

The Institution was charged by Congress with the disbursement of the following appropriations for the year ending June 30, 1913:

International exchanges	$32,000
American ethnology	42,000
Astrophysical Observatory	13,000
National Museum:	
Furniture and fixtures	50,000
Heating and lighting	50,000
Preservation of collections	300,000
Books	2,000
Postage	500
Building repairs	10,000

National Zoological Park_____ $100, 000
Bridge over Rock Creek, National Zoological Park_____ 20, 000
International Catalogue of Scientific Literature_____ 7, 500

    Total_____ 627, 000

In addition to the above specific amounts to be disbursed by the Institution, there was included under the general appropriation for public printing and binding an allotment of $74,900 to cover the cost of printing and binding the annual report and other Government publications issued by the Institution, and to be disbursed by the Public Printer.

RESEARCHES AND EXPLORATIONS.

The Smithsonian Institution has continued to carry on field work in various lines throughout the world by means of small allotments from its funds. It has also accomplished a great deal in the way of exploration and research through the generosity of friends of the Institution, who have contributed funds for special work or provided opportunities for participation in explorations which they had undertaken personally or through the aid of others. Each year, however, the Institution is obliged to forego opportunities for important investigations through lack of sufficient funds.

I can here only briefly mention some of the explorations and researches in progress during the past year. Accounts of activities connected with the Astrophysical Observatory, the Bureau of American Ethnology, and the United States National Museum are given in other parts of this report by those in direct charge of those branches of the Institution.

LANGLEY AERODYNAMICAL LABORATORY.

At a meeting of the Board of Regents on May 1, 1913, the following resolutions were adopted:

Whereas the Smithsonian Institution possesses a laboratory for the study of questions relating to aerodynamics, which has been closed since the death of its director, the late Dr. S. P. Langley, formerly Secretary of the Smithsonian Institution; and

Whereas it is desirable to foster and continue, in the Institution with which he was connected, the aerodynamical researches which he inaugurated:

Resolved, That the Board of Regents of the Smithsonian Institution hereby authorizes the Secretary of the Institution, with the advice and approval of the executive committee, to reopen the Smithsonian Institution laboratory for the study of aerodynamics and take such steps as in his judgment may be necessary to provide for the organization and administration of the laboratory on a permanent basis.

That the aerodynamic laboratory of the Institution shall be known as the Langley Aerodynamical Laboratory.

That the functions of the laboratory shall be the study of the problems of aerodronics, particularly those of aerodynamics, with such research and ex-

perimentation as may be necessary to increase the safety and effectiveness of aerial locomotion for the purposes of commerce, national defense, and the welfare of man.

That the secretary is authorized to secure, as far as practicable, the cooperation of governmental and other agencies in the development of aerodromical research under the direction of the Smithsonian Institution.

The Regents also authorized the secretary to appoint an advisory committee; to add, as means are provided, other laboratories and agencies; to group them into a bureau organization; and to secure the cooperation with them of the Government and other agencies.

In accordance with the above general plan an advisory committee was organized at a meeting convened at the Institution on May 23, 1913. The official status, organization, agencies, resources, and facilities of this committee are set forth in a statement reprinted in the appendix to the present report.

In preparing plans for carrying forward investigations in various lines a study is being made of researches in progress in other countries, and an allotment has been made from the Hodgkins fund for the maintenance, in part, of the laboratory.

STUDIES IN CAMBRIAN GEOLOGY AND PALEONTOLOGY.

During the field season of the fiscal year 1912–13, or the spring and summer of 1913, I continued my geological work in the Canadian Rockies. A month was spent in the Robson Park district of British Columbia, and Jasper Park, Alberta, our camp being on the continental divide near Berg Lake, northwest of the Yellowhead Pass, through which the Grand Trunk Pacific and Canadian Northern Railways have been built.

Considerable collections of fossils were made at several localities, photographs were taken, and several places in the geological section studied in 1912 were examined. This was rendered necessary by reason of my having been driven out of the region by continued rain and snow storms the previous year.

From the Robson district I went to Burgess Pass, north of Field, British Columbia, and worked at the Middle Cambrian fossil quarry until late in the season. Both in the Robson district and also at Burgess Pass I was assisted by my two sons, Sidney and Stuart, who have had many years' experience in field work in the Rocky Mountains. Mr. R. D. Mesler, of the United States National Museum, spent nearly the entire field season collecting at Burgess Pass. Special effort was made to finish collecting at this famous locality, and at the close of the field season a collection of several thousand specimens weighing over two and a half tons was shipped to Washington.

GEOLOGICAL SURVEY OF PANAMA.

A plan has been formulated and some progress has been made in certain lines of field work for a geological survey of Panama, under the joint auspices of the Isthmian Canal Commission, the United States Geological Survey, and the Smithsonian Institution, and an allotment has been made from the Institution's funds toward the expenses of such investigation. The general plan of the survey comprises a systematic study of the physiography, stratigraphy and structural geology, geologic history, geologic correlation, mineral resources (including coal, oil, and other fields), petrography and paleontology of the Canal Zone, and of as much of the adjacent areas of the Isthmian region as is feasible. In this survey an opportunity is afforded for working out in detail the succession of the geologic formations and the study of the structure, petrography, and paleontology of a Central American area such as has never before existed, and probably never will be realized again. It is possible to make and properly characterize a standard geologic section of this part of the world, one with which the more obscure exposures of adjacent areas may be compared. There is already nearly completed a section of each side of the Culebra Cut in a horizontal scale of 1 : 5,000, vertical scale 1 : 2,500; and a general section has been made from the Atlantic to the Pacific, with collections from every fossiliferous exposure seen. A basis has been practically determined for the intercorrelation of the formations across the Isthmus and for correlation with the Gulf States, also with certain formations in some of the West Indian Islands.

Upon the completion of this survey the Institution will publish a general account of the work accomplished, and later it is planned to print a detailed report of the geological data of the Isthmus and adjoining regions.

BIOLOGICAL EXPEDITIONS IN AFRICA.

Rainey African expedition.—The Paul J. Rainey expedition in British East Africa came to a successful close in February, 1912. The collections, numbering 5,750 large and small mammals, 400 birds, 2,000 reptiles, and 500 miscellaneous specimens, included a large number of new genera and species since described in the publications of the Institution and the National Museum. During this expedition Mr. Edmund Heller, of the National Museum, who had previously served as naturalist on the expedition under Col. Roosevelt, was the guest of Mr. Rainey, who provided him all the native assistants that he could use, and accorded him perfect freedom as regards choice of collecting ground. Mr. Heller was thus able to visit the exact regions from which material was most needed to supplement that procured

by the previous expedition. After studying the mammals in the British Museum, Mr. Heller reports that the United States National Museum now has the finest series of East African mammals in the world. Eighty lions were secured on the expedition, which more than tripled the highest previous record for Africa.

The Childs Frick Expedition.—As mentioned in my last report, Dr. Edgar A. Mearns, United States Army, associate in zoology in the National Museum, who had served on the expedition under Col. Roosevelt, accompanied Mr. Childs Frick, of New York, on a hunting and collecting trip in the territory north of that visited by Col. Roosevelt and Mr. Rainey, covering at the same time certain parts of Abyssinia, northern British East Africa, and the country lying about Lake Rudolf. The expedition ended in September, 1912. The collections as a whole embraced plants, mammals, birds, reptiles, batrachians, fishes, mollusks, crustaceans, and other invertebrates. A part of the large collection of birds obtained by this expedition is deposited in the National Museum.

EXPLORATIONS IN BORNEO.

Abbott Borneo expedition.—Through the generosity of Dr. W. L. Abbott, who for many years was engaged in natural history and ethnological investigations in the Malay Archipelago, a fund has been provided for natural history field work in Dutch East Borneo.

Nothing has been published concerning this practically unknown region, and the National Museum had no collections from East Borneo, although there were a few from the west and south coasts of Borneo. During the past year Mr. Raven, in charge of this exploration, succeeded in securing a very interesting series of the characteristic mammals of the country, such as orangs, deer, wild pigs, squirrels and smaller rodents, and other interesting species.

Mr. Streeter's exploration in Borneo.—Mr. Daniel Denison Streeter, jr., of Brooklyn, having offered his services as a collaborator in zoology of the National Museum, sailed from New York on April 4, 1912, and returned December 24, 1912. Some of his thrilling experiences in the interior of Borneo are described in his interesting report to the Institution. He passed from Sarawak into Dutch Borneo by ascending the Rejang River and crossing the mountains on the dividing line to the Kajan River. He then ascended to the head of this river and crossed another range to the headwaters of the Mahakam River, which he descended to the Strait of Macassar. During his trip he secured some interesting collections of mammals, reptiles, and anthropological specimens, part of which have been received by the Museum, but many additional specimens were necessarily left behind in the mountains and may not be recovered.

In describing his journey Mr. Streeter writes:

Arriving at Kuching, the capital of the Kingdom of Sarawak, in north-western Borneo. I apprised the officials of my plan to cross Borneo. They helped me with every means in their power, although they told me that no man had ever yet been across Borneo, and that they did not think it possible for me to do it. * * * I crossed a bay 200 miles wide in a Chinese junk to the mouth of the Rejang River. Here I engaged three Malays and their canoe to take me 80 miles up the river to the island of Sibu. * * * A little Malay river steamer arrived and took me 90 miles farther up the river—as far as it could go. At this head of navigation is a little native town called Kapit, and here I again took to dugout canoes, this time for good and all. * * * It took me two months to ascend this river to its headwaters. I collected specimens of reptiles and mammals, together with interesting anthropological specimens, took photographs of all kinds, studied the natives, the rivers, the weather, vegetable life in general, made notes on everything, and mapped my course as accurately as I could with the instruments in my possession. * * * I crossed the main range of mountains forming the backbone of Borneo to the headwaters of the Kajan River. I estimate the altitude of the pass through which I crossed the mountains at a little over 3,000 feet. * * * [He then proceeded] in dugout canoes down one branch of the Kajan River and up the main river for several days to the immense village of Long Nawong. This village comprises about 3,000 souls, ruled by a native rajah, who visited me and with whom I exchanged presents. Here I set out with one canoe and five head-hunters as paddlers and continued up the Kajan River. A flood arose, my canoe went to the bottom, and we had to swim for shore. I saved my rifle and my tin box of maps, papers, diaries, and notes.

Continuing on foot up the river we fell in with a party of 40 head-hunters of the Bahau Tribe and I arranged to travel with them, sending back my five Kajan paddlers. With this Bahau troupe I continued up the Kajan River to its headwaters and over another range of mountains to the headwaters of the Mahakam River. * * * After losing my collection I immediately began a second collection, and this assumed the proportions of the first as I proceeded. When within about 500 miles of the mouth of the Mahakam River I came to the first outpost of civilization, the Dutch military post of Long Iram, in charge of a Dutch captain and a company of native Javanese. Upon hearing my story the captain promised to send a military expedition up into the interior, where the Dutch had never been before, and try and secure the outfit which I had left at these native villages. * * * I boarded a little flat-bottomed Malay river steamer, which * * * floated on down the river to the coast.

LYMAN SIBERIAN EXPEDITION.

The expedition to the Altai Mountains, which was financed by Dr. Theodore Lyman, of Cambridge, Mass., as mentioned in my last report, returned to Washington September 16, 1912. Mr. Ned Hollister, a naturalist of the National Museum, accompanied Dr. Lyman. The expedition resulted in securing 350 mammals for the National Museum and 300 birds for the Museum of Comparative Zoology, Cambridge. The region covered was in the Kurai district, Government of Tomsk. The mammal collection is one of the most important received in recent years, as the region had not been represented in the Museum, and the fauna was of special interest on account of its close relationship with that of North America.

ANTHROPOLOGICAL STUDIES IN SIBERIA AND MONGOLIA.

With the view of securing further information as to the origin of the race that peopled America, a visit was made to certain portions of Siberia and Mongolia by Dr. Hrdlička, of the National Museum, during the summer of 1912. This work was undertaken partly under the auspices of the Smithsonian Institution and partly in the interest of the Panama-California Exposition of San Diego.

Besides field observations made by Dr. Hrdlička, an examination was made of the anthropological collections in the various Siberian museums in the region covered. He saw or was told of thousands upon thousands of burial mounds, or "kourgans," dating from the present time back to the period when nothing but stone implements were used by man in those regions. And he saw and learned of numerous large caverns, particularly in the mountains bordering the Yenisei River, which yield human remains and offer excellent opportunities for investigation.

A brief account of Dr. Hrdlička's studies is given by him in a pamphlet published in the Smithsonian Miscellaneous Collections, in which he says:

In regard to the living people, the writer had the opportunity of seeing numerous Buriats, representatives of a number of tribes on the Yenisei and Abacan Rivers, many thousands of Mongolians, a number of Tibetans, and many Chinese, with a few Manchurians. * * * Among all these people there are visible many and unmistakable traces of admixture or persistence of what appears to have been the older population of these regions, pre-Mongolian and especially pre-Chinese, as we know these nations at the present day. Those representing these vestiges belong partly to the brachycephalic and in a smaller extent to the dolichocephalic type, and resemble to the point of identity American Indians of corresponding head form. * * *

The physical resemblances between these numerous outcroppings of the older blood and types of northeastern Asia and the American Indian can not be regarded as accidental, for they are numerous as well as important, and can not be found in parts of the world not peopled by the yellow-brown race; nor can they be taken as an indication of American migration to Asia, for emigration of man follows the laws of least resistance or greatest advantage, and these conditions surely lay more in the direction from Asia to America than the reverse.

In conclusion, it may be said that from what he learned in eastern Asia, and weighing the evidence with due respect to other possible views, the writer feels justified in advancing the opinion that there exist to-day over large parts of eastern Siberia, and in Mongolia, Tibet, and other regions in that part of the world, numerous remains, which now form constituent parts of more modern tribes or nations, of a more ancient population (related in origin, perhaps, with the latest paleolithic European), which was physically identical with and in all probability gave rise to the American Indian.

BIOLOGICAL SURVEY OF THE PANAMA CANAL ZONE.

The biological survey of the Panama Canal Zone, organized by the Institution in 1910, was brought to a close during the past year as

far as field work was concerned, and some of the results have been published. The natural history collections made by the survey have added very valuable material to the National Museum series of mammals, birds, fishes, reptiles, and amphibians, land and fresh-water mollusks, flowering plants and ferns, and specimens of microscopic plant and animal life.

ANTHROPOLOGICAL STUDIES IN PERU.

During the past year a second trip was made to Peru by Dr. Hrdlička in continuation of the brief but very interesting researches made by him in that country in 1910. The principal objects of the trip were the mapping out as far as possible of the anthropological distributions of the prehistoric Peruvian, more particularly the coast people; the determination of the physical type of the important Nasca group of people, which represent one of the highest American cultures; further inquiry as to man's antiquity on the west coast of South America; and the extension of Dr. Hrdlička's researches on pre-Columbian pathology. Important collections were made for the National Museum, as well as for the Panama-California Exposition at San Diego. A very perceptible change for the worse was observed in the state of preservation of the ancient remains, both skeletal and archeological. Dr. Hrdlička reports:

The major part of the old population of the extensive coast region were found everywhere to belong to the brachycephalic type, intimately related to the Maya-Zapotec type in the north. The Nasca people were one of the purest groups belonging to this type. Wherever they lived these people of the Peruvian coast were wont to practice, more or less, the anteroposterior head deformation. They have spread along the valleys to the foothills of the Cordillera, and have probably in some instances penetrated into the mountains. Meanwhile, however, they became in many though not all localities more or less mixed, or rather mingled, with dolicho or near dolichocephalic elements which came from or across the mountains.

As to man's antiquity, the results were wholly negative; no trace of man of geological age, nor even of an ancient man of the present epoch, were discovered. The density of the pre-Columbian population was in some localities greater, in others probably less, than at the present time.

As to pathology, the people of the mountains were found to have been much healthier than those of the coast. The most common disease leaving its traces on the bones in ancient Peru was arthritis. In strictly pre-Columbian cemeteries there was no rachitis, syphilis, tuberculosis, or cancer. Wounds of skull were very common. In the mountains numerous interesting instances of trepanation were discovered.

Further explorations in the mountainous parts of Peru are urgent.

RESEARCHES UNDER THE HODGKINS FUND.

As mentioned in my last report, a limited grant was made from the Hodgkins fund for carrying on certain observations on nocturnal radiation at various altitudes. The results of this research, as also

of several other lines of investigation in connection therewith, provided for by an additional grant, are discussed on another page by Mr. Abbot in his report on the Astrophysical Observatory. There was also allotted from the Hodgkins fund a grant for carrying on aeronautical researches in connection with the Langley Aerodynamical Laboratory, discussed in other paragraphs.

There was in press at the expense of this fund during the year a paper by Dr. Leonard Hill and associates, discussing the results of important researches made by them in London on the influence of the atmosphere of crowded places upon our health and comfort.

SMITHSONIAN TABLE AT NAPLES ZOOLOGICAL STATION.

In order to afford an opportunity for American biologists to study marine life under exceptionally favorable facilities, the Institution for 20 years past has maintained a table at the Naples Zoological Station. Investigators are assigned the use of this table for stated periods on the recommendation of an advisory committee appointed for the purpose. The authorities of the station have on several occasions courteously allowed more than one occupant of the table when there was overlapping in periods of appointment.

During the year covered by the present report Mr. Sidney I. Kornhauser and Mr. Edward C. Day, both of Harvard University, have pursued studies at the Smithsonian table.

THE HARRIMAN TRUST FUND.

Under a special trust fund, established by Mrs. E. H. Harriman, for his investigations in natural history and ethnology, Dr. C. Hart Merriam has equipped two offices, the principal one at Washington, D. C., the other at Lagunitas in west central California, a convenient center for field work on the Pacific coast and a favorable place for the preparation of results.

His principal work during the year has been a continuation of a monographic study of the American bears. Assistance in the way of the loan of specimens has been rendered by all of the larger museums of America, including the Government museums of Canada, at Ottawa and Victoria, and by a number of sportsmen and hunters, who have placed their private material at his disposal. This has been still further augmented by the purchase of specimens, mainly skulls, of rare and little known species, some of which are the only ones in existence. In view of the fact that several species of our large bears are already extinct and others on the verge of extinction, the great value of this material is obvious.

In connection with the study of the big bears a new method has been developed. namely, an intensive study of teeth from photographs. Owing to the large size of bear skulls, it is impossible to

bring the teeth of several individuals near enough together to admit a direct comparison. To obviate this difficulty, the teeth have been photographed natural size. Series of these photographs arranged closely side by side permit direct critical comparison of a number of specimens at one time, favoring the recognition of resemblances and differences not easily detected from the specimens. This method would seem to be available in the case of other groups of large mammals.

Owing to the desirability of completing the study of the bears as early as possible, but little field work was undertaken. Still, a few tribes of Indians were visited, and half a dozen vocabularies collected, completing the series of vocabularies of the 25 existing linguistic stocks of California and Nevada.

AMERICAN SCHOOL OF ARCHEOLOGY IN CHINA.

At a meeting held at the Smithsonian Institution on January 3, 1913, there was discussed the establishment of an American school of archeology in China. The objects of the school as proposed are: (1) To prosecute archeological research in eastern China; (2) to afford opportunity and facilities for investigation to promising and exceptional students, both foreign and native, in Asiatic archeology; and (3) to preserve objects of archeological and cultural interest in museums in the countries to which they pertain in cooperation with existing organizations, such as the Société d'Ankor, etc.

The management of the affairs of the school was placed in the hands of an executive committee of five, consisting of Dr. Charles D. Walcott, Secretary of the Smithsonian Institution; Mr. Charles Henry Butler, reporter of the United States Supreme Court; Dr. Harry Lane Wilson, of Johns Hopkins University; Mr. Charles L. Freer, of Detroit; and Mr. Eugene Meyer, jr., of New York. The general committee consists of 15 gentlemen especially interested in archeological research in China, with Dr. Walcott as chairman and Mr. Butler as secretary. Arrangements were made for a preliminary survey in the Chinese Republic for the information of the general committee in considering the permanent organization of the proposed school.

PUBLICATIONS.

The publications issued by the Smithsonian Institution and its branches during the last fiscal year made a total of 6,260 printed pages, and the aggregate distribution comprised 182,883 copies of pamphlets and bound volumes.

The Institution accomplishes one of its principal objects, "the diffusion of knowledge," by means of its several series of publications which record results of original researches, accounts of explorations, the progress achieved in science and industry, and general informa-

tion in all branches of human knowledge believed to be of value to those interested in the promotion of science and the welfare of man.

The Smithsonian Contributions to Knowledge, in quarto form, and the Smithsonian Miscellaneous Collections, in octavo, are printed at the expense of the Smithsonian fund, and necessarily in limited editions, being distributed chiefly to certain large libraries throughout the world, where they are available for public reference. The Smithsonian Annual Report, however, is printed at the expense of congressional appropriations, and in an edition of several thousand copies, thus permitting its wide distribution. The principal feature of the annual report is a general appendix containing about 30 selected or original memoirs illustrating the more remarkable and important developments in the physical and natural sciences, as well as showing the general character of the operations of the Institution.

In addition to the publications mentioned above, there are several other series of works issued under the direction of the Institution through its various branches or bureaus. These include the Annual Report, and the Proceedings and Bulletin of the National Museum; the Contributions from the National Herbarium; the Annual Report and Bulletins of the Bureau of American Ethnology; and the Annals of the Astrophysical Observatory, all of which are Government publications, being printed through annual allotments by act of Congress.

Smithsonian Contributions to Knowledge.—The chief characteristic of memoirs printed in the Contributions to Knowledge is that they are records and discussions of original investigations and constitute important additions to knowledge. Since the establishment of this series in 1848, about 150 of these memoirs have been published in 35 quarto volumes. The most recent memoir of this series, reviewed in my last report, was the "Langley Memoir on Mechanical Flight," recording the experiments of the late Secretary Langley, which resulted in his successful demonstration of the practicability of aerial navigation with machines heavier than air.

Smithsonian Miscellaneous Collections.—In this series 40 papers were issued, forming parts of five volumes, the titles of which are enumerated in the appendix herewith. Among these numerous papers were two articles by the secretary describing further results of his studies of Cambrian fossils, a bibliography of the geology and mineralogy of tin, and a large number of papers descriptive of results of the Smithsonian African expedition under Col. Roosevelt, the Paul J. Rainey African expedition, and the Smithsonian biological survey of the Panama Canal Zone. There were also in press at the close of the year three additional papers on Cambrian fossils, one of them, in particular, giving an account of the Mount Robson region; and a paper, as already mentioned, by Dr. Leonard Hill and other

investigators of the Physical Laboratory of the London Hospital Medical College, discussing the results of experiments to determine " The influence of the atmosphere on our health and comfort in confined and crowded places." The authors conclude that—

No symptoms of discomfort, fatigue, or illness results, so long as the temperature and moisture are kept low, from air rendered, in the chemical sense, highly impure by the presence of human beings. Such air can be borne for hours without any evidence of bodily or mental depression. * * * Heat stagnation is therefore the one and only cause of the discomfort, and all the symptoms arising in the so-called vitiated atmosphere of crowded rooms are dependent on heat stagnation. The moisture, stillness, and warmth of the atmosphere are responsible for all effects, and all the efforts of the heating and ventilating engineer should therefore be directed toward cooling the air in crowded places and cooling the bodies of the people by setting the air in motion by means of fans. * * * The essentials required of any good system of ventilation are, then: (1) Movement, coolness, proper degree of relative moisture of the air, and (2) reduction of the mass influence of pathogenic bacteria. The chemical purity of the air is of very minor importance and will be adequately insured by attendance to the essentials.

Smithsonian Report.—The completion of the annual report for 1911 was long delayed at the Government Printing Office, awaiting a supply of the quality of paper used in that publication. The general appendix of the volume contained 36 articles of the usual character. The report for 1912 was in type at the close of the fiscal year. The popularity of this work continues unabated, the entire edition each year becoming exhausted very soon after its publication.

National Museum publications.—The publications by the Museum during the year comprised two volumes of Proceedings, pamphlet copies of 96 articles from the Proceedings, two Bulletins, and nine parts of volumes of Contributions from the National Herbarium. An interesting work in press at the close of the year, prepared by Assistant Secretary Richard Rathbun, gives a descriptive account of the building recently erected for the departments of natural history of the United States National Museum. The book is illustrated with 34 plates and, besides a general description of the building, includes special chapters relating to structural details and mechanical equipment.

Zoological nomenclature.—Opinions 52 to 56 rendered by the International Commission on Zoological Nomenclature were published in the usual form. The Institution also continues to aid the work of this commission by providing funds for clerical services in connection with the office of its secretary in this country.

Publications of the Bureau of American Ethnology.—The publications issued by the Bureau of American Ethnology were the Twenty-eighth Annual Report, containing papers on Casa Grande, the antiquities of the upper Verde River and Walnut Creek Valleys, Ariz.,

the linguistics of Algonquian tribes; also Bulletin 52 on early man in South America, and Bulletin 54 on the physiography of the Rio Grande Valley, New Mexico.

The Astrophysical Observatory had completed work on volume 3 of the Annals of the Observatory at the close of the year, and it was expected that the distribution of the edition would take place soon after July 1.

Reports of historical and patriotic societies.—In accordance with the national charters of the American Historical Association and the National Society of the Daughters of the American Revolution, annual reports of those organizations were submitted to the Institution and communicated to Congress.

Allotments for printing.—The allotments to the Institution and its branches, under the head of "Public printing and binding," during the fiscal year, aggregating $74,900, were all utilized with the exception of small balances on work in progress at the close of the year. The allotments for the year ending June 30, 1914, are as follows:

For the Smithsonian Institution, for printing and binding annual reports of the Board of Regents, with general appendixes_____ $10,000
For the annual reports of the National Museum, with general appendixes, and for printing labels and blanks, and for the bulletins and proceedings of the National Museum, the editions of which shall not exceed 4,000 copies, and binding, in half turkey or material not more expensive, scientific books and pamphlets presented to or acquired by the National Museum library_____ 37,500
For the annual reports and bulletins of the Bureau of American Ethnology, and for miscellaneous printing and binding for the bureau_ 21,000
For miscellaneous printing and binding:
    International exchanges _____ 200
    International catalogue of scientific literature_____ 100
    National Zoological Park_____ 200
    Astrophysical Observatory (any unexpended balance of 1913 allotment for volume 3 of Annals made available for fiscal year 1914)_ 200
For the annual report of the American Historical Association_____ 7,000

    Total_____ 76,200

Committee on printing and publication.—The advisory committee on printing and publication under the Smithsonian Institution has continued to examine manuscripts proposed for publication by the branches of the Institution and has considered various questions concerning public printing and binding. Twenty-two meetings of the committee were held during the year and 138 manuscripts were passed upon. The personnel of the committee as now organized is as follows: Dr. Frederick W. True, Assistant Secretary of the Smithsonian Institution, chairman; Mr. C. G. Abbot, Director of the Astrophysical Observatory; Dr. Frank Baker, Superintendent of the National Zoological Park; Mr. A. Howard Clark, editor of the Smithsonian Institution, secretary of the committee; Mr. F. W. Hodge,

ethnologist in charge of the Bureau of American Ethnology; Dr. George P. Merrill, head curator of geology, United States National Museum; and Dr. Leonhard Stejneger, head curator of biology, United States National Museum.

Distribution of publications.—On August 23, 1912, a law was enacted requiring that all Government publications must, after October 1, be mailed from the Government Printing Office, mailing lists or labels to be forwarded to the superintendent of documents for that purpose. In accordance with the law, the Smithsonian Report and publications of the United States National Museum and the Bureau of American Ethnology have since been distributed direct from the Government Printing Office. The accumulated stock of publications, aggregating about 100,000 volumes and pamphlets from which constant demands had been supplied, was also transferred to the superintendent of documents during the month of September.

Catalogue of publications.—There is in preparation, and nearly ready for press, a complete list of publications of the Institution and its branches. Partial lists have been issued from time to time but no complete catalogue has been published. The present work will contain about 12,000 titles, being practically a table of contents of the entire series of Contributions to Knowledge, Miscellaneous Collections and Annual Reports of the Institution, the Proceedings, Bulletins, and Annual Reports of the National Museum, the Annual Reports and Bulletins of the Bureau of American Ethnology, and the Annals of the Astrophysical Observatory. The catalogue is so arranged as to permit of ready reference to any desired subject or the collective works of any author appearing in the several series.

LIBRARY.

During the year 12,930 volumes and parts of volumes, chiefly on scientific topics, were added to the Smithsonian deposit in the Library of Congress. The additions to the National Museum library numbered 4,062 volumes and pamphlets. Additions were also made to the libraries of the Astrophysical Observatory, the Zoological Park, the Bureau of American Ethnology, and other office libraries, including the aeronautical library, which it is expected will be utilized chiefly in connection with the work of the Langley Aerodynamical Laboratory organized in May, 1913.

The appropriations for the next fiscal year provide an item of $15,000 for beginning the construction of metal book stacks in the main hall of the Smithsonian building to contain the library of the Bureau of American Ethnology, a part of the National Museum library, and certain other collections of books now stored in places inconvenient for reference.

In the new building of the National Museum four rooms on the ground floor have been provided with steel book stacks and library appliances of the latest design. To these rooms have been transferred works needed in connection with natural history studies, while books relating chiefly to the arts and industries and to American history are retained in the older Museum building, where the collections of those classes remain on exhibition.

ARCHIVES.

During the year some attention was given to improving conditions in the archive room of the Institution, which was very badly over-crowded. This room, on the fourth floor of the Smithsonian building, was thoroughly overhauled and much accumulated material not re-lating directly to the history of the Institution was removed to other quarters. The set of Smithsonian publications formerly preserved in this room was temporarily removed to the office of the assistant secretary in charge of library and exchanges, thus making space for manuscript material of importance. Two large wooden cases con-taining papers relating to the internal affairs of the Institution and its branches, together with other documents, were replaced by metal cases containing drawers equipped with uniform cardboard recep-tacles for papers, and alphabetical guide cards. It was not found possible, however, to complete the transfer of the papers to these receptacles during the year.

The wooden panels in the doors of the wall cases in the room were removed and replaced by glass, so that it is possible to see .the con-tents of the cases without opening them. A case was provided for maps, plans. charts, and other large objects.

Cases were placed in an adjoining room for the reception of dupli-cate vouchers and other financial papers of the several branches of the Institution.

The large quantity of Schoolcraft papers at present in the custody of the Institution were transferred to uniform file boxes and placed on shelves. These papers are only partially classified.

The archives are now completely accessible, although a large amount of work is still required to put them into thoroughly satis-factory condition. The principal improvements needed. are a com-plete card catalogue of the several classes of papers contained in the room, with indications of the location of each, and a uniform card index of the contents of the bound volumes of official letters, both originals and press copies. A reclassification of a considerable portion of the other archives is also desirable, as well as the comple-tion of the work of transferring papers to the new cases mentioned above.

LANGLEY MEDAL.

In memory of the late Secretary Samuel Pierpont Langley and his contributions to the science of aerodromics, the Board of Regents of the Smithsonian Institution on December 15, 1908, established the Langley medal, " to be awarded for specially meritorious investigations in connection with the science of aerodromics and its application to aviation." The first award of the medal was voted by the Board of Regents on February 10, 1909, to Wilbur and Orville Wright " for advancing the science of aerodromics in its application to aviation by their successful investigations and demonstrations of the practicability of mechanical flight by man." The medal was presented to each of the brothers Wright at a meeting of the board on February 10, 1910.

The second award of the medal was voted on February 13, 1913, to Mr. Glenn H. Curtiss " for advancing the art of aerodromics by his successful development of a hydroaerodrome whereby the safety of the aviator has been greatly enhanced," and to Monsieur Gustave Eiffel " for advancing the science of aerodromics by his researches relating to the resistance of the air in connection with aviation." The presentation of these medals was made on May 6, 1913. This date was selected in order that the ceremonies incident to the presentation might take place in connection with the observance of " Langley Day," which was established by the Aero Club of Washington in 1911, to commemorate the achievement by Mr. Langley on May 6, 1896, of mechanical flight by a heavier-than-air machine propelled by its own power. On May 6, 1911, and again on May 6, 1912, there were exhibition flights of biplanes and monoplanes near Washington. On the afternoon of May 6, 1913, the celebration by the club occurred at the Army War College immediately after the exercises in the Smithsonian building, and consisted of a reception by the Aero Club, followed by hydroaeroplane, biplane, and monoplane maneuvers.

The presentation exercises in the Smithsonian building preceded the unveiling of the Langley memorial tablet and included addresses by Dr. Alexander Graham Bell in presenting the medals, and acceptances by Ambassador Jusserand in behalf of M. Eiffel, and by Mr. Glenn H. Curtiss.

In the course of his address M. Jusserand said :

We have seen France and America vie with each other not only in the conquest of better, greater, and safer liberty from year to year, but also in the producing of more and more momentous inventions, improving the plane of life of the many, reaching less faulty solutions of the great social problems.

Nothing more striking has taken place on these lines than in what concerns the conquest of the air. It is surely appropriate to remember that one of the very first flights ever attempted took place in Versailles, when one of the earliest baloons rose a fortnight after the treaty definitely securing your independence had been signed there in 1783. And you all know that Franklin, when

asked, What was the good of such an invention, answered, "What is the good of a new-born child?" The child has grown and is rapidly becoming a giant in power. There is no branch of human activity in which France and America have more truly vied with each other than this one, from the memorable day of the *Montgolfière*, so quickly perfected by the French physicist Charles, to our own time.

Mr. Curtiss said in part:

As I look at the Langley models here, it becomes more evident to me than ever before—the merit of these machines and the great work which Mr. Langley did. We now know, as a result of M. Eiffel's laboratory experiments, that flying planes used by Prof. Langley had a great deal of efficiency, and it is also generally known that the Langley machines, as he built them, had more inherent stability than the models which those of us who followed after Langley used in our first flights. I can not say too much in favor and in memory of Prof. Langley.

LANGLEY MEMORIAL TABLET.

On May 6, 1913, the anniversary of the successful flight of the Langley model aerodrome in 1896, the Langley memorial tablet to commemorate the aeronautical work of the late Secretary Langley, was unveiled in the Smithsonian building in the presence of men prominent in the development of aviation and a large company of invited guests. The tablet was described in my last report. On the occasion of the unveiling of the tablet a memorial address was delivered by Dr. John A. Brashear, one of Prof. Langley's oldest and most cherished friends, and his warm supporter during his long investigations connected with the subject of aerial flight.

CONGRESSES AND CELEBRATIONS.

The Institution each year receives invitations to numerous scientific congresses and celebrations in the United States and abroad, but as funds are not available for the expenses of delegates, few of these invitations can be accepted. In some instances, however, it is possible to arrange for representation by collaborators of the Institution who are visiting the localities, or by members of the scientific staff of the Institution or its branches who are attending at their own expense.

Zoological Congress.—Dr. Leonhard Stejneger, Dr. Ch. Wardell Stiles, and Dr. Herbert Haviland Field were designated to represent the Smithsonian Institution and National Museum and were also designated by the Department of State as delegates on the part of the United States at the Ninth International Congress of Zoology at Monaco, March 25 to 30, 1913.

Applied chemistry.—The opening meeting of the Eighth International Congress of Applied Chemistry was held in Washington on September 4, 1912, with subsequent meetings in New York. Prof. F. W. Clarke was designated to attend the congress as the representative of the Institution. The congress made the Secretary of the Institution one of its honorary vice presidents.

Prehistoric anthropology.—Dr. Aleš Hrdlička, Dr. Charles Peabody, and Dr. George Grant MacCurdy were designated to represent the Smithsonian Institution and the United States at the Fourteenth International Congress of Prehistoric Anthropology and Archeology at Geneva, September 9 to 15, 1912.

Hygiene and demography.—The Fifteenth International Congress on Hygiene and Demography was held in Washington from September 23 to 28, 1912, under the auspices of the Government of the United States, President William Howard Taft serving as honorary president. Your secretary was a member of the local committee on organization, and Mr. W. H. Holmes, of the National Museum, served on the interdepartmental committee on exhibits.

Archeological Congress.—The Third International Congress on Archeology was held at Rome, October 9 to 16, 1912. Upon the nomination of the Smithsonian Institution the Department of State designated Prof. A. L. Frothingham, of Princeton, Prof. George M. Whicher, secretary of the New York Society of the Archeological Institute of America, and Mr. William H. Buckler, president of the Baltimore Society of the Archeological Institute of America, as delegates on the part of the United States at that congress.

Historical studies.—Prof. J. Franklin Jameson, of the American Historical Association, was designated to act as the representative of the Smithsonian Institution at the International Congress of Historical Studies held in London, April 3 to 8, 1913, under the auspices of the British Academy in cooperation with British universities, learned societies, and institutions.

Geological Congress.—Your secretary, as a member of the Twelfth International Congress of Geology, arranged to be at Toronto August 7 to 14, 1913, and was appointed to represent the Carnegie Institution of Washington and the Washington Academy at that congress. Dr. George P. Merrill, head curator of geology in the National Museum, was appointed a representative of the Smithsonian Institution.

Congress of Americanists.—Arrangements have been progressing during the year in connection with the Nineteenth International Congress of Americanists, which has been invited to meet in Washington in 1914, and Mr. W. H. Holmes, Mr. F. W. Hodge, and Dr. Aleš Hrdlička have been appointed an auxiliary committee to represent the Smithsonian Institution in connection with the preliminary details respecting the proposed meeting.

The State education building at Albany was dedicated October 16, 1912, on which occasion the secretary presented the formal congratulations of the Smithsonian Institution, which is specially interested in the city of Albany, for it was there that Joseph Henry, first secretary of the institution, was born in the year 1799, and there Henry began his researches and experiments in electricity

which in great measure made possible the wonderful electrical achievements of the present day. " He married the intensity magnet to the intensity battery, the quantity magnet to the quantity battery, discovered the law by which their union was effected, and rendered their divorce impossible." The intensity magnet is that which is to-day in use in every telegraph system. " Henry's oscillating machine was the forerunner of all our modern electrical motors. The rotary motor of to-day is the direct outgrowth of his improvements in magnets."

National Academy of Sciences.—The semicentennial meeting of the National Academy of Sciences was held at the Smithsonian Institution April 22 to 24, 1913. The exercises included an address of welcome by Dr. Ira Remsen, president of the academy, and addresses on " The Relation of Science to the Higher Education in America," by President Arthur T. Hadley, of Yale University; " International Cooperation in Research," by Dr. Arthur Schuster, of London; " The Earth and Sun as Magnets," by Dr. George E. Hale, of the Mount Wilson Solar Observatory; and " The Structure of the Universe," by J. C. Kapteyn, of Groningen. At the White House, President Woodrow Wilson and Dr. R. S. Woodward participated in the ceremony of the presentation of medals awarded by the academy. The Watson medal was awarded to Prof. J. C. Kapteyn, the Draper medal to M. Henri Deslandres, the Agassiz medal to Dr. Johan Hjort, and the Comstock prize to Prof. R. A. Millikan. There were various social functions in connection with the meeting, including an evening reception in the natural history building of the National Museum. On the occasion of the meeting of the academy there was published "A History of the First Half Century of the National Academy of Sciences, 1869–1913," prepared and edited by Dr. Frederick W. True, assistant secretary of the Smithsonian Institution.

Imperial Russian Museum.—On the occasion of the fiftieth jubilee of the Imperial Moscow and Rumiantsef Museum your secretary was elected an honorary member of that institution.

GEORGE WASHINGTON MEMORIAL BUILDING.

In the public buildings bill approved by the President on March 4, 1913, permission was granted to the George Washington Memorial Association to erect a building on the square formerly occupied by the Pennsylvania railway station in Washington. The preamble of the original bill (S. 5494), as passed by the Senate April 15, 1912, defined the objects of the Memorial Building as follows:

To provide a site for the erection of a building to be known as the George Washington Memorial Building, to serve as the gathering place and headquarters of patriotic, scientific, medical, and other organizations interested in promoting the welfare of the American people.

Whereas George Washington, on July ninth, seventeen hundred and ninety-nine, said: " It has been my ardent wish to see a plan devised on a liberal scale which would spread systematic ideas through all parts of this rising Empire," and it was Washington's wish to materially assist in the development of his beloved country through the promotion of science, literature, and art, and with the firm conviction that " knowledge is the surest basis of public happiness " ; and

Whereas the changing conditions that time has brought require new methods of accomplishing the results desired by Washington and now a necessity of the American people; and

Whereas at the present time there is not any suitable building in the city of Washington where large conventions or in which large public functions can be held, or where the permanent headquarters and records of national organizations can be administered; and

Whereas a building should be provided in which there shall be a large auditorium, halls of different sizes where all societies pertaining to the growth of our best interests can meet, and such as it is deemed desirable may have permanent headquarters; and

Whereas the George Washington Memorial Association is now engaged in obtaining funds for the erection and endowment of a building suitable for the purposes above set forth, to be known as the George Washington Memorial Building: Therefore   *   *   *

The law as passed by Congress and approved by the President March 4, 1913, was as follows:

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled:

*   *   *   *   *   *   *

Sec. 10. That a building is hereby authorized to be erected in the District of Columbia, to be known as the George Washington Memorial Building.

The control and administration of said building, when erected, shall be in the Board of Regents of the Smithsonian Institution.

The George Washington Memorial Association is authorized to erect said building in accordance with plans to be procured by said association and to be approved by the Commission of Fine Arts, said building to be fireproof, faced with granite, and to cost not less than $2,000,000; it shall have an auditorium that will seat not less than six thousand people, and such other smaller halls, reception rooms, office rooms, and so forth, as may be deemed necessary to carry out the purposes for which the building is erected. And the said George Washington Memorial Association shall in addition provide a permanent endowment fund of not less than $500,000, to be administered by the Board of Regents of the Smithsonian Institution, the income from which shall, as far as necessary, be used for the maintenance of the said building.

Permission is granted the George Washington Memorial Association to erect said building in the north end of the reservation known as Armory Square, bounded by Sixth and Seventh Streets west and B Street north and B Street south. The south front of said building is to be on a line with the south front of the new National Museum Building, in the north end of the Smithsonian Park; and the said land is hereby set apart for that purpose: *Provided,* That the actual construction of said building shall not be undertaken until the sum of $1,000,000 shall have been subscribed and paid into the treasury of the George Washington Memorial Association: *And provided further,* That the erection of said George Washington Memorial Building be begun within a period of two years from and after the passage of this act, and this section shall be null and

void should the George Washington Memorial Association fail to comply with the provisions thereof which are conditions precedent to the authorization herein granted.

Said building may, among other purposes, be used for inaugural receptions and special public meetings authorized by Congress.

Congress may alter, amend, add to, or repeal any of the provisions of this section.

The need in Washington of such a structure as here authorized has been urged on many occasions in public meetings throughout the country. The Regents of the Smithsonian Institution have expressed their willingness to administer it when completed. It will be a gathing place and headquarters for patriotic, scientific, medical, and other organizations interested in promoting the welfare of the American people and the development of the country in science, literature, and art.

Plans for the building are being made, and it is hoped that the work of construction will begin within the time limit set by the law.

THE NATIONAL MUSEUM.

The operations of the National Museum are discussed with such detail by Assistant Secretary Rathbun in the appendix to the present report that I need here refer only to some of the more important features of the year.

The completion of the natural history building, with its spacious well-lighted halls, has made it feasible to vastly improve the extensive exhibits of the departments of anthropology, biology, and geology installed therein; while objects pertaining to the industrial arts and to American history are now given ample exhibition room in the older building.

In the zoological halls of the new building are exhibited a number of groups of animals which are noteworthy examples of the art of taxidermy, some of these groups being made up of specimens received from the Smithsonian African expedition under Col. Roosevelt. And likewise in the halls devoted to anthropological exhibits are shown a number of racial groups of mankind, including several representing Indians of various tribes engaged in their native games and mechanical occupations, which seem particularly attractive to visitors.

The department of arts and industries for many years had been checked in its development by what seemed to be the more urgent demand for space for natural history exhibits. Many large and interesting collections illustrative of the industrial arts, acquired by the Museum during the last 30 years, had therefore necessarily been held in storage, but the transfer of objects of natural history to the new building has now released large halls for the installation

of instructive collections pertaining to art textiles, silk, wool, and cotton manufactures, to arms and armor, ceramics, mineral technology, and to some other general manufacturing industries, including an exposition of the processes and of the raw materials and finished products.

The responses received from requests for objects desired to complete particular series in this department are very gratifying and indicate a public interest in its still broader development. The educational character of these exhibits, and, in fact, of all objects displayed in the National Museum, is kept constantly in mind. Thus, a small number of specimens or objects well arranged is found to be far better than a large display where the educational feature is overshadowed by what may be termed a picturesque method of installation. The style of cases, the color of the background, and many other details must be carefully studied and worked out with a view to proper harmony in every respect.

There has been added to the Museum collections an approximate total of 302,133 specimens and objects, as compared with 238,000 during the year preceding. The accessions included 140,015 botanical, 113,509 zoological, and 14,716 paleontological specimens, besides a number of paintings, art textiles, useful plant products, and objects illustrative of American history.

In geographical range the accessions covered practically the entire world, ethnological, archeological, biological, and geological objects being received from all parts of North and South America, from Alaska, Siberia, China, Oceanica, Dutch East Indies, Africa, and other lands, the results in large measure of explorations undertaken by the Smithsonian Institution and National Museum either directly or in cooperation with private individuals or Government departments. Among individuals who have thus served the Museum during the year, some of whom I have already mentioned, were Mr. Childs Frick, who made collections, especially of birds, in Africa; Dr. Theodore Lyman, who hunted animals in the Altai Mountains in Asia; Dr. W. L. Abbott, who continued his collecting work in Kashmir and generously provided for field work in Borneo; Mr. D. D. Streeter, jr., who explored the interior of Borneo; Mr. George Mixter, who visited Lake Baikal in Siberia; and Mr. Copley Amory, jr., who made collections of mammals and of fossil species in Alaska.

One of the interesting additions to the mammal division was a mounted specimen and skeleton of the rare okapi of Africa. Several noteworthy collections of fossil invertebrates were also received, and among accessions of vertebrate remains were a large series of mammals from the Fort Union beds of Montana, and many genera and species from recently uncovered Pleistocene cave deposits in Maryland; also a series of bones from the Yukon territory containing

the first evidence of the former extension of the range of the camel beyond the Arctic Circle.

The most important permanent addition to the division of history was the gift by Mr. Eben Appleton of the " Star Spangled Banner," which he had allowed to be exhibited as a loan since 1907. This great flag, about 30 feet square, is the one that waved over Fort McHenry in September, 1814, and inspired Francis Scott Key to write the national anthem.

The division of physical anthropology has received several large and valuable accessions of skeletal remains during recent years, one of the most important recent additions being obtained in Mongolia, where the curator was engaged in studies to discover the probable origin of the American Indians.

The National Gallery of Art was enriched by the gift of 12 paintings, 7 of them presented by Mr. William T. Evans, and by 18 paintings and 2 marble sculptures received as loans from friends of the Gallery.

It has been the custom for many years to distribute to schools and colleges for teaching purposes, or to exchange with other institutions, such duplicate natural history specimens as are no longer needed for scientific study by the Museum staff. During the past year about 30,000 specimens were thus utilized for educational purposes or to secure new material for the Museum.

The number of visitors to the new building during the year was 261,636 on week days and 58,170 on Sundays, the largest attendance being 13,236 on March 5, the day following the inauguration of the President.

The publications issued by the Museum included about 100 papers from the Proceedings and a number of Contributions from the National Herbarium, besides two completed volumes of Proceedings and two Bulletins. The total distribution of earlier and current publications was 71,600 copies.

Mention is made on another page of the fitting up of rooms in the new building for the accommodation of such portions of the Museum library as pertain chiefly to natural history subjects, books on other topics being retained in the older buildings. The total contents of the library at the close of the year was 43,692 volumes and 72,042 papers of all kinds.

Meetings of various scientific organizations were held in the Museum auditorium and adjacent rooms, and there were several formal receptions which· are noted in the report of the assistant secretary.

BUREAU OF AMERICAN ETHNOLOGY.

Ethnological researches have been continued in accordance with law, among the American Indians and the natives of Hawaii, includ-

ing the excavation and preservation of archeological remains. The systematic researches carried on by eight ethnologists of the regular staff and by specialists not officially connected with the bureau covered a wide range of field work and office studies, which are described in such detail in the appendix by the ethnologist-in-charge, that I need here to review but briefly some of the most important activities of the year. For the preparation of a memoir on The Culture History of the Aborigines of the Lesser Antilles, Dr. Fewkes visited Trinidad, Barbados, St. Vincent, and other islands of the West Indies, where he made extensive excavations of shell-heaps, particularly in Trinidad and St. Vincent, yielding very interesting collections of pottery and other objects, and carried on archeologic studies which proved to be especially important in throwing light on the material culture of the former aborigines of the coast adjacent to South America.

Studies were continued in the investigation of Indian population, a research covering the whole period from the first occupancy of the country by white people to the present time, and including the entire territory from the Rio Grande to the Arctic Ocean. A monograph in preparation on this subject includes chapters on notable epidemics, vital statistics, and race admixture.

Further interesting studies were made in New Mexico in preparation of a memoir on the philosophy, anthropic worship and ritual, zoic worship, social customs, material culture, and history of that interesting and conservative Pueblo people known as the Tewa Indians.

A large amount of additional material was also obtained concerning the languages, myths, and legends of the Fox Indians and other Algonquian tribes, and on the ceremonies and rituals of the Osage and Pawnee Indians.

Progress has been made in the preparation of the Handbook of American Indian Languages and the Handbook of American Archeology. There is also in preparation a Handbook of Aboriginal Remains East of the Mississippi.

Some of the results of investigations conducted by the bureau in cooperation with the School of American Archeology are described in three memoirs, now published or ready for publication, on The Physiography of the Rio Grande Valley, New Mexico, in Relation to Pueblo Culture, The Ethnobotany of the Tewa Indians, and the Ethnozoology of the Tewa Indians, and there is also in process of completion in this connection a manuscript entitled " An Introduction to the Study of the Maya Hieroglyphs."

The Handbook of American Indians, completed by the bureau a few years ago, has increased the popular interest in our aborigines to such an extent that the bureau is considering the feasibility of issuing a series of treatises devoted to the Indians of the respective

States, and as a beginning for such a series there is in preparation a Handbook of the Indians of California.

Among the publications issued during the year may be mentioned the Twenty-eighth Annual Report; a reprint of the Handbook of American Indians North of Mexico, ordered by resolution of Congress; a bulletin on Early Man in South America; portions of Part 2 of the Handbook of American Indian Languages; and a bulletin on Chippewa Music.

The scope of the work undertaken by the bureau is necessarily limited by the funds available. Among investigations that are specially desirable to extend may be mentioned the exploration and preservation of antiquities, including the cliff dwellings in the arid region; ethnological researches in Alaska; the extension of ethnological investigations among the tribes of the Mississippi drainage; and excavation and study of archeological remains in the South and West.

INTERNATIONAL EXCHANGES.

The work of the International Exchange Service shows a steady gain from year to year. During the last 15 years the weight of matter handled has increased from 317,883 pounds in 1898 to 593,969 pounds in 1913, and the total number of packages has increased during that period from 84,208 in 1898 to 338,621 in 1913. As compared with the year 1908, 66 per cent more packages were handled in 1913 and 678 more boxes were dispatched, but by practicing various economies and improving methods the increased work has been accomplished without an increase in the annual appropriation.

In addition to the international exchange of publications between Governments and institutions of learning, the service has from time to time been called upon by foreign Governments and societies to secure information on particular subjects. To answer such inquiries has sometimes required much correspondence. Thus, in a recent instance, the minister of public works and mines in a distant country sought information through the Department of State on laws and regulations with respect to the boring, mining, and storage of petroleum in the United States, a class of data which the Smithsonian Institution was able to obtain only by writing to the principal States concerned in that industry.

In order to simplify the shipment of exchanges to the Union of South Africa arrangements have been made whereby packages are now shipped in bulk to the Government Printing Works at Pretoria for distribution instead of being sent to miscellaneous addresses in the various provinces of the Union. This method will effect a saving to the Institution in freight charges and improve the service with South Africa. A similar method would be very advantageous with the Commonwealth of Australia and is now under consideration by

the Australian House of Representatives and the chairman of the library committee of that country.

In Egypt there has been organized the Government publications department at Cairo, to which consignments for distribution there are now being forwarded. In Mexico a service of exchanges has been established in the department of public works.

Full sets or partial sets of United States official documents are now sent to 92 foreign depositories, the Province of Bombay, the Corporation of Glasgow, Finland, British Guiana, the Free City of Lubeck, and the Province of Madras having been added to the list during the year. There has also been carried on since 1909, through the Exchange Service, an interparliamentary exchange of official journals with legislative chambers agreeing thereto, 100 copies of the daily issue of the Congressional Record being provided for that purpose. Thirty-two countries have so far agreed to this exchange of their official journals.

NATIONAL ZOOLOGICAL PARK.

The National Zoological Park was established by act of Congress in 1890 " for the advancement of science and the instruction and recreation of the people." It was the outgrowth of a small collection of living animals which for several years had been assembled in low sheds and small paddocks adjacent to the Smithsonian building, where they were kept primarily for scientific study, though they were likewise a constant source of interest to the public. There was at once a rapid increase in the size of this collection when the animals were removed to the spacious grounds provided for them in the beautiful Rock Creek Valley, and it is evident from its increasing popularity during the last 23 years that the establishment of this great zoological park has been regarded as a wise investment of public funds.

The popular interest in the park has continued to be very great. On Sundays and holidays the walks and buildings are crowded. During the past year the number of visitors was 633,526, and the daily average in the month of March, 1913, was 3,900. One hundred and forty-two classes, schools, etc. numbering 5,579 pupils, visited the park during the year with the definite purpose of studying the animals.

The interests of science have also been primary objects of attention in the administration of the park. A number of species of American animals which were rapidly becoming extinct are here preserved in appropriate natural surroundings. In a recent report I called attention to a much needed improvement that should be made in the erection and equipment of a laboratory and hospital in the park

whereby the welfare of the animals could be more thoroughly guarded, and where investigations of a zoological nature could be prosecuted for the increase of practical and scientific knowledge.

The number of animals of all kinds in the park collections on June 30, 1913, was 1,468, representing 154 species of mammals, 202 species of birds, and 31 species of reptiles, which are enumerated in detail on another page in the report of the superintendent. The important additions during the year included a pair of young African elephants, three dromedaries, a pair of cheetahs, several species of gazelles, and other animals from the Government Zoological Garden at Giza, Egypt; 7 ostriches from southern California; and 2 moose, a male and a female, from the Rocky Mountains National Park in Alberta.

Among the improvements completed in the park during the year was an outdoor parrot cage constructed through the generosity of Mr. John B. Henderson, jr., one of the regents of the Institution. An inclosure was also built for the ostriches recently received and one for the wood ducks and related species. Mention should also be made of the erection of a stone building, 24 by 40 feet, equipped for the cooking of food for the animals by boiling or baking, and also for cold storage. The building is abundantly lighted and thoroughly sanitary, and is a great improvement over the inadequate quarters heretofore used for food preparation.

An appropriation of $20,000 was included in the sundry civil act for 1913 for the construction of a stone-faced or bowlder bridge across Rock Creek to replace the log bridge erected in 1896 on the line of the roadway from Adams Mill Road. A contract for the construction of the new bridge was entered into on May 29, 1913, and work was begun soon after the close of the fiscal year. The bridge will be 80 feet in span and about 40 feet wide. It will be built of reenforced concrete faced with rough blocks of the blue gneiss found in this region, the stone for the concrete being obtained in the park.

In the sundry civil act for the fiscal year 1914 provision is made for the purchase of about 10⅔ acres of land to extend the west boundary of the park to Connecticut Avenue. The acquisition of this land has been urged for several years as a much-needed addition to the area of the Zoological Park.

THE ASTROPHYSICAL OBSERVATORY.

The Astrophysical Observatory continued during the past year the important investigations begun during the administration of the late Secretary Langley to determine the solar constant of radiation and the variability of the sun. In his account of the operations of the observatory on another page of this report Director Abbot dis-

cusses the results of these researches up to the present time and concludes that the observations at Bassour, Algeria, taken in connection with those made simultaneously at Mount Wilson, Cal., have established the variability of the sun. He concludes also that a variability connected with the sun-spot cycle has been shown.

Observations were also made to determine the effects of volcanic eruptions on climate. Soon after the eruption of Mount Katmai, Alaska, in June, 1912, the presence of dust in the upper air from this volcano was indicated both in California and in Algeria, and in August the direct radiation of the sun was found to be reduced about 20 per cent by the interposition of the dust cloud. Mr. Abbot and Mr. Fowle discuss the results of their observations and the general subject of " Volcanoes and Climate " in a paper in the Smithsonian Miscellaneous Collections. They conclude that a combination of the effects of sun spots and volcanic haze accounts for all the principal irregularities in the temperature of the earth for the last 30 years.

In connection with observations on nocturnal radiation it became necessary to determine the temperature and humidity prevailing above certain stations. This was accomplished with the cooperation of the United States Weather Bureau through the use of sounding balloons and captive balloons carrying to high altitudes self-recording apparatus for measuring the temperature, pressure, and humidity of the air.

There was completed during the year volume III of the Annals of the Astrophysical Observatory, recording the work accomplished from 1907 to 1913.

INTERNATIONAL CATALOGUE OF SCIENTIFIC LITERATURE.

There is administered by the Smithsonian Institution through a small annual appropriation by Congress, the United States Bureau of the International Catalogue of Scientific Literature. This is one of the 33 regional bureaus whose function it is to collect, index, and classify all scientific publications of the year in each country and to send the classified references to the central bureau in London, where, since 1901, they have been collated and published in a series of 17 annual volumes which form an index to current scientific literature.

The catalogue is not of a commercial character, but by economical methods of administration, and partly through the revenue obtained from subscriptions to the series of volumes, it is hoped that the enterprise will be self-supporting with the exception of the general expenses of the regional bureaus in gathering the data.

The United States bureau sent to the central bureau during the past year 27,995 cards, making a total of 290,330 cards forwarded from this country since the work was begun in 1901. The total number of classified citations received at the central bureau in London from 1901 to 1913 was about 2,500,000.

Although the congressional appropriation for the bureau is intended primarily for maintaining a purely scientific international enterprise, yet, without added expense, the bureau is of value to the public as a source of general information on many scientific subjects. The Smithsonian Institution is in constant receipt of requests for information on a very great variety of topics, and since it is the purpose of the International Catalogue to collect and classify the published results of scientific investigation many of these inquiries are referred for reply to this bureau.

NECROLOGY.

JAMES SCHOOLCRAFT SHERMAN.

At the annual meeting of the Regents on December 12, 1912, the following resolutions were adopted to the memory of Vice President Sherman:

Whereas the Board of Regents of the Smithsonian Institution have received the sad intelligence of the death on October 30, 1912, of James Schoolcraft Sherman, Vice President of the United States and Chancellor of the Institution, therefore, be it

Resolved. That in the passing away of this distinguished official the country has lost a man whose unsullied public career and blameless private life marked him as one of the best exemplars of the highest type of American patriotism and citizenship; while this Institution has been deprived of the association of a Regent and presiding officer whose loyalty to its purposes and zeal in its interests have been an inspiration to his colleagues.

Resolved, That we tender to the family of Mr. Sherman our respectful and sincere sympathy in their great bereavement,

Resolved, That an engrossed copy of these resolutions be transmitted to the family of the late chancellor.

James Schoolcraft Sherman, LL.D., born in Utica, N. Y., October 24, 1855, became a Regent of the Smithsonian Institution upon taking the oath of office as Vice President of the United States on March 4, 1909, and was elected Chancellor of the Institution on December 8, 1910, as successor to Chancellor Melville Weston Fuller, Chief Justice of the United States, who died July 4, 1910. Mr. Sherman received the degree of LL.B. from Hamilton College in 1878 and LL.D. in 1903. He was admitted to the bar in 1880 and practiced his profession at Utica; was mayor of Utica, 1884–85; Member of Congress, 1887 to 1891 and 1893 to 1909, and was elected Vice President November 3, 1908. He had been trustee of Hamilton College since 1905, and held important positions of trust in his native city.

JOHN BROOKS HENDERSON.

At a special meeting of the Regents on May 1, 1913, a resolution was adopted in memory of the Hon. John B. Henderson, who served as a Regent from January 26, 1892, to March 1, 1911, when he felt obliged to retire from active duties on account of failing health. His sound judgment and wise counsel as chairman of the executive committee and as member of the permanent committee had been of great assistance to the board throughout his long term of service. Mr. Henderson was born near Danville, Va., on November 26, 1826, and died at Takoma Park, District of Columbia, on April 12, 1913. He was United States Senator from Missouri from 1862 to 1869, and filled many other honorable positions during earlier and later periods of his life. He had been a resident of Washington City since 1890.

Respectfully submitted.

CHARLES D. WALCOTT, *Secretary.*

APPENDIX 1.

REPORT ON THE UNITED STATES NATIONAL MUSEUM.

SIR: I have the honor to submit the following report on the operations of the United States National Museum for the fiscal year ending June 30, 1913:

IMPORTANT MATTERS OF THE YEAR.

Although many important matters developed, as usual, in connection with the operations of the Museum during last year, those of chief general interest related to the exhibition collections in the new building and to the progress of work in the department of arts and industries. As explained in the last report, only the first and second stories of the new building, with an aggregate floor area of 185,294 square feet, are being utilized at present for the permanent installations, which, with a single exception, relate wholly to natural history. The last of this space was opened to the public during April, 1913, but to a certain extent the exhibits still remain incomplete and the arrangements provisional. The plan of three wings particularly adapts this building to the three departments of anthropology, biology, and geology, representing the organization of the natural history collections, each of which has been allotted an entire wing for its exhibition series, the overflow from each being continued into the adjacent ranges.

Of the several branches which are administered in the department of anthropology, three have been established in the new building as constituting what is now commonly recognized in museum classification as one of the great divisions of natural history. They are physical anthropology, ethnology, and archeology. Physical anthropology is not yet represented in the public halls, though an important installation of a technical character has been provided in the laboratory. Each of the other subjects, however, has been extensively illustrated on a popular though none the less instructive basis, to which purpose a total floor area of 65,941 square feet has been assigned. Ethnology occupies the entire available space allotted to the department in the first story, namely, the northern section of both ranges, and all parts of the north wing surrounding the picture gallery, which is temporary in its location here. The total area covered is 35,474 square feet. The arrangement is geographical, and the ex-

hibits find their key in family groups placed centrally in the halls. The archeological collections are displayed in the second story, the Old World series, both historic and prehistoric, occupying the eastern side and northern end of the wing to the extent of about 7,927 square feet, and the New World series the eastern side of the wing and the entire east range, with a floor area of 22,540 square feet. The exhibition of North American archeology is especially full and important.

The classification of the biological exhibits, at present restricted to zoology, comprises five principal and several minor subdivisions, of which the most extensive consists of a comprehensive representation of all the main groups of animals, each arranged faunally. Next follow a systematic series, a series illustrating comparative anatomy and osteology which is practically subsidiary to it, a series of domestic animals, and a faunal series for the District of Columbia. These are supplemented by a number of special exhibits illustrating interesting phases in zoology and noteworthy features of the collection. The entire amount of space assigned to the department is 64,398 square feet, of which the faunally arranged exhibit utilizes 41,058 square feet. The mammals in this collection occupy the first floor of the west wing, with the exception of a small area in which the series of birds begins, the latter extending thence through the western section of the west range; while the reptiles, batrachians, fishes, and invertebrates are installed in the second story of the wing. On the northern side of the wing is the collection of comparative anatomy and osteology, followed successively in the west range by the systematic series, the domestic animals, and the faunal exhibit of the District of Columbia, the special exhibits being provided for in alcoves on the court side of the range.

The geological exhibits are classified under four subjects, namely, systematic or physical and chemical geology, applied geology, mineralogy and paleontology. Besides the east wing, of which they have entire possession, they occupy only the eastern section of the adjoining range in the first story, the combined area amounting to 47,691 square feet. Systematic geology is displayed in the range, while applied geology, including the most complete series of building and ornamental stones in the country, and mineralogy, with the beginnings of an excellent representation of gems and precious stones, are accommodated in the second story of the wing. In the lower story, which is wholly devoted to paleontology, the fossil vertebrates, with many skillfully prepared remains of extinct animals and several large and striking skeletons, occupy the large sky-lighted hall and eastern end of the wing, the fossil invertebrates the southern side of the wing, and the fossil plants the northern side.

In the matter of reorganizing the several industrial collections which were long ago displaced through the overcrowding of the older buildings in which they are now being rearranged, excellent progress was made despite the limited means available. The division of mineral technology, which had been nominally recognized for several years and for which a large amount of valuable material has been held in storage, was actively established, but not until late in the year. In the division of textiles, in which the work was started over a year earlier, the results accomplished have been sufficient to very materially attract public notice. The old collection, including also certain animal and vegetable products, was first unpacked, and, although much of it had so greatly deteriorated as to be rendered useless, there remained an excellent nucleus to build upon, the material being chiefly serviceable for its bearing on the history and development of the subjects represented. It was extensively drawn upon in preparing a preliminary exhibition series, which was practically completed before the close of the fiscal year 1912. During last year there was marked activity in the acquisition of new material, in the extension of the exhibition collections, and in the general work of the division. Many of the leading manufacturers were advised with, and their cordial approval of the plans and the substantial support they have already given the Museum insures beyond question the building up of a thoroughly practical representation of the textile and allied industries. The accessions of the year covered a wide range of materials and manufacture, and included raw materials, intermediate stages, and finished products, as well as illustrations of various processes. They were almost wholly from American sources, among the exceptions being an instructive exhibit of the woolen industry of Bradford, England, and another of native Filipino handicraft in the making of mats, baskets, hats, fabrics, and other useful articles. In lines other than textiles the additions related mainly to the utilization of rubber, and included many testimonials to Charles Goodyear, whose name is indissolubly connected with the origin and early advancement of this important industry. The installation of textiles kept pace with the receipt of materials, and by the close of the year a very notable and attractive exhibition had been assembled, mainly in the south hall of the older building.

COLLECTIONS.

The total number of specimens acquired during the year was approximately 302,132, of which 26,999 pertained to the several subjects covered by the department of anthropology; 113,509 were zoological, 140,015 botanical, 5,569 geological, and 14,716 paleontological; while 12 were paintings for the National Gallery of Art, and 1,312 were textiles and useful plant products for the department of

arts and industries. Several important loans for exhibition, consisting mainly of historical and ethnological objects and paintings, were also received.

The additions in ethnology came mainly from the Philippine Islands and other parts of the Far East, from Paraguay and Dutch Guiana, and from the middle and western United States. Maine, Pennsylvania, Maryland, Virginia, and Kentucky were chiefly represented in the contributions to prehistoric archeology, while Egyptian and Greco-Roman antiquities and small lots of materials from various European localities composed the principal acquisitions in historic archeology. The division of physical anthropology received valuable accessions, mainly of skeletal remains, from many sources, the most noteworthy consisting of a large collection made by the curator in Mongolia. In the division of mechanical technology the most extensive additions were to the section of firearms and other weapons, and included several early and rare pieces; while in the division of graphic arts they were illustrative of recent methods of pictorial reproduction. Most prominently to be noted in connection with the division of history was the gift by Mr. Eben Appleton of "The Star Spangled Banner," which had been exhibited as a loan since 1907. This witness of the gallant defense of Fort McHenry during its unsuccessful bombardment by the British fleet on September 13 and 14, 1814, immortalized by the stirring verses of Francis Scott Key, has been accorded a conspicuous place of honor in the principal hall of history. Among other notable acquisitions were memorials of the Washburn family and of Generals U. S. Grant and Frederick D. Grant; a bronze cannon, with its wooden carriage, brought to America by General Lafayette and used in the Revolution; over 21,000 postage stamps and postal cards, added to the large collection from the Post Office Department; the *Titanic* memorial gold medal issued by the Carnegie Hero Fund Commission; and, as a loan, the collection of historical china assembled by the late Rear Admiral F. W. Dickins, United States Navy, consisting of about 500 pieces, and including a large number of fine examples of presidential china from the administration of Washington to that of Benjamin Harrison.

For some of its most important acquisitions the department of biology was indebted to several expeditions to distant regions, conducted at private expense. The most extensive of these, undertaken by Mr. Childs Frick, who was accompanied by Dr. E. A. Mearns, United States Army (retired), and others, visited Abyssinia and British East Africa, and was absent from January to September, 1912. The birds obtained, numbering over 5,000, have been deposited in the Museum. On a hunting trip to the region of the Altai Mountains, in Asia, Dr. Theodore Lyman, of Harvard University, with

the assistance of Mr. N. Hollister, of the Museum staff, secured about 650 specimens of mammals and birds, which have been shared between the Museum of Comparative Zoology and the National Museum. Dr. W. L. Abbott, who continued his collecting work in Kashmir, also maintained a naturalist in Borneo to extend the field work which he had so effectively carried on for several years. From the former region a large number of small mammals were received during the year, and from the latter many specimens of mammals, birds, and reptiles. Mr. Arthur de C. Sowerby transmitted mammals and reptiles from China; Mr. D. D. Streeter, jr., collected mammals and reptiles in Borneo; Mr. George Mixter visited Lake Baikal, Siberia, and its vicinity, securing specimens of the native bear, of the seal peculiar to the lake, and of a number of small mammals; and Mr. Copley Amory, jr., joining a Coast Survey party in Alaska, obtained many mammals, including several caribou and an interesting series of bones of fossil species. Mr. A. C. Bent in the course of investigations in Newfoundland and Labrador made collections of birds, and Dr. Paul Bartsch and Dr. T. Wayland Vaughan, as guests on the Carnegie steamer *Anton Dohrn*, collected marine invertebrates among the Florida Keys, as did also Mr. John B. Henderson, jr., by means of dredgings from his yacht *Eolis*. Mr. Paul G. Russell, of the division of plants, who accompanied an expedition of the Carnegie Institution to the West Indies, secured for the Museum several thousand botanical specimens.

The division of mammals was fortunate in obtaining an exceptionally fine mounted specimen and skeleton of the rare okapi from the Kongo region of Africa. The principal accessions of fishes and marine invertebrates were from explorations by the Bureau of Fisheries in various parts of the Pacific Ocean, consisting mainly of collections that had been studied and described. Among fishes were the types of 110 new species, while the marine invertebrates included extensive series of crustaceans and echinoderms, besides ascidians and plankton material from the Atlantic coast. Mollusks were received from various localities in North America and from the Bahama Islands, Venezuela, South Australia, and the Dutch East Indies. Of insects over 37,000 specimens were acquired, including 15,000 forest insects from West Virginia, valuable material from India and Great Britain, and about 10,000 well-prepared beetles from the District of Columbia, which are intended to be used in connection with the exhibition series of the local fauna. The division of plants was enriched to the extent of 140,000 specimens. The principal addition consisted of some 80,000 specimens of grasses, transferred by the Department of Agriculture, which, with 12,800 specimens purchased during the year and the material previously in the herbarium, places the Museum in possession of the largest and most

comprehensive collection of grasses in this country. Other important accessions were the Wooton collection of 10,000 plants mostly from New Mexico, about 10,000 West Indian plants, a valuable series from British Guiana, and the C. Henry Kain collection of diatoms, one of the finest in the world, and supposed to be the largest in the United States.

The more important additions to the department of geology were illustrative of published results of investigations by the Geological Survey, comprising rocks, ores, and minerals from some of the Western States, and fossils from the middle Devonian of New York, the early Devonian and Silurian of Maine, and the Ordovician of Tennessee. Other noteworthy collections of fossil invertebrates received were from the Silurian and Devonian of the Detroit River region, the Silurian of Ohio, and the Tertiary of the Panama Canal Zone, while of vertebrate remains the accessions included a large series of mammals from the Fort Union beds of Montana, many genera and species from recently uncovered Pleistocene cave deposits in Maryland, and a small but interesting series of bones from the Yukon territory containing the first evidence of the former extension of the range of the camel on this continent beyond the Arctic Circle. The Geological Survey transmitted a large collection of Cretaceous and Tertiary plants from Colorado and New Mexico, containing 271 type and illustrated specimens. Large collections of Cambrian fossils were made by Secretary Walcott in British Columbia and Alberta in connection with his geological work in the Canadian Rockies.

NATIONAL GALLERY OF ART.

The permanent additions to the Gallery consisted of 12 paintings, 10 of which were gifts and 2 bequests. Of the former, 7 were received from Mr. William T. Evans as contributions to his notable collection of the work of contemporary American painters and are as follows: " The Meadow Brook," by Charles Paul Gruppe; " The Mourning Brave," by Edwin W. Deming; " The Fur Muff," by Robert David Gauley; " Water Lilies," by Walter Shirlaw; " Castle Creek Canyon, South Dakota," by Frank De Haven; and " Christ before Pilate " and " Suffer the Little Children to Come unto Me," by Otto W. Beck, the last two being pastels. The other gifts were " Twilight after Rain," by Norwood H. MacGilvary, presented by Mr. Frederic F. Sherman in memory of Eloise Lee Sherman; " The Wreck," by Harrington Fitzgerald, donated by the artist; and " The Lace Maker," after Terburg, contributed by Miss Julia H. Chadwick. The bequests consisted of the " Tomb of ' Mahomet the Gentleman ' at Broussa," by Hamdy Bey, from Mrs. Elizabeth C. Hobson; and a portrait from the widow of the late Col. Albert B. Brackett, United States Army, by G. P. A. Healy. The additions to the loan collec-

tion comprised 18 paintings and 2 marble sculptures received from 12 friends of the Gallery.

<div align="center">ART TEXTILES.</div>

The lace exhibit now embraces a fairly connected series both in respect to the varieties of laces and the development of the industry, and it also contains some important examples which from their quality and rarity form striking museum pieces. Though smaller and less conspicuous in the matter of display material than some others, it ranks high among the museum collections of the country. The work during the year was mainly in the direction of securing a more systematic arrangement of the collection and of more fully labeling both specimens and cases. The collection at present consists chiefly of loans, which have increased in number from year to year, with the expectation of soon making the collection more permanent in character.

<div align="center">MISCELLANEOUS.</div>

Duplicate specimens to the number of about 7,300 were distributed to schools and colleges for teaching purposes, the subjects represented being mainly fishes, insects, marine invertebrates, rocks, ores, minerals, and fossils. Some 1,500 pounds of material suitable for blowpipe and assay work by students was also similarly disposed of. Over 21,000 duplicates were used in making exchanges, about 85 per cent of this number being plants. Two hundred and six lots of specimens were sent to specialists for working up both on behalf of the Museum and in the interest of the advancement of researches by other institutions. They comprised over 12,700 individual specimens, besides several hundred packages of unassorted material, principally of animals, plants, and fossils.

The aggregate number of visitors to the new building on week days during the year was 261,636, a daily average of 836, and on Sundays 58,170, a daily average of 1,118. The attendance at the older Museum building was 173,858, and at the Smithsonian building 142,420, these figures representing a daily average of 555 for the former and of 455 for the latter. During inaugural week in March, 1913, the daily average for the new building was increased to 5,325 persons, the largest attendance for any single day having been 13,236 on March 5.

The publications consisted of Bulletins 79 and 81 and volumes 42 and 43 of the Proceedings, besides 105 papers issued in separate form, of which 96 belonged to the series of Proceedings and 9 to the Contributions from the National Herbarium. Thirty-five papers on Museum subjects, mainly descriptive of new additions to the collections, were also published in the Smithsonian Miscellaneous Collections. The number of copies of Museum publications distributed, including earlier issues as well as those of the year, was about 71,600.

The furnishing of the library quarters in the new building was completed early in the autumn of 1912, and the transfer of the books and equipment intended to be kept there was soon afterwards accomplished. While designed primarily to accommodate the natural history and anthropological publications, which comprise the major part of the collection, this has also been constituted the main or central library, where most of the general works of reference will be placed and where all publications will be received and catalogued. The library in the older building will hereafter be mainly restricted to the subjects of history and the arts and industries. The accessions of the year consisted of 1,690 books, 2,213 pamphlets, and 159 parts of volumes, which increased the total contents of the library to 43,692 volumes and 72,042 unbound papers of all kinds.

The facilities afforded by the new building for meetings and other functions were frequently availed of. The auditorium and committee rooms were used for the regular meetings of the Anthropological Society of Washington, the Washington Society of the Fine Arts, and the Spanish-American Atheneum, and for a course of lectures under the Naval War College Extension. The annual meeting and semicentennial anniversary of the National Academy of Sciences were held in April. Of congresses and other assemblages which were accommodated wholly or in part in the building were the Fifteenth International Congress on Hygiene and Demography; the Ninth Triennial Congress of American Physicians and Surgeons; a joint meeting of the American Philological Association, the Archaeological Institute of America, and the Society of Biblical Literature and Exegesis; a meeting of the American Farm-Management Association; the Twentieth Annual Convention of the International Kindergarten Union; and a meeting of the General Federation of Women's Clubs. The Department of Agriculture had the use of the auditorium for annual conferences on farm management and meat inspection. Besides similar functions in connection with two of the above meetings, receptions were given by the Regents and Secretary to the members in attendance at the Eighth International Congress of Applied Chemistry and the Sixth International Congress for Testing Materials, and to the Daughters of the American Revolution. On the evening of March 6 Mr. James Wilson, late Secretary of Agriculture, was tendered a reception by the employees of the Department of Agriculture.

Respectfully submitted.

RICHARD RATHBUN,
Assistant Secretary in Charge, U. S. National Museum.

Dr. CHARLES D. WALCOTT,
Secretary of the Smithsonian Institution.

NOVEMBER 12, 1913.

REPORT ON THE BUREAU OF AMERICAN ETHNOLOGY.

SIR: I have the honor to submit the following report of the opera-
tions of the Bureau of American Ethnology during the fiscal year
ended June 30, 1913, which have been conducted by authority of the
act of Congress approved August 24, 1912, making appropriations for
sundry civil expenses of the Government, and in accordance with a
plan of operations approved by the Secretary of the Smithsonian
Institution. The act referred to contains the following provision:

American ethnology: For continuing ethnological researches among the
American Indians and the natives of Hawaii, including the excavation and
preservation of archæologic remains, under the direction of the Smithsonian
Institution, including salaries or compensation of all necessary employees and
the purchase of necessary books and periodicals, including payment in advance
for subscriptions, $42,000.

SYSTEMATIC RESEARCHES.

The systematic researches were conducted by the regular staff of
the bureau, consisting of seven ethnologists, and by other specialists
not directly connected with the bureau. These operations may be
summarized as follows:

Mr. F. W. Hodge, ethnologist-in-charge, was occupied almost en-
tirely during the year with administrative affairs pertaining to the
bureau's activities. He was able to devote some time to the prepara-
tion of the Bibliography of the Pueblo Indians, the writings relating
to the subject covering so extended a period (from 1539 to date) and
being so numerous that much remains to be done. He devoted atten-
tion also, as opportunity offered, to the revision of certain sections of
the Handbook of American Indians, but as it is the desire to revise
this work completely, with the aid of the entire staff of the bureau as
well as of other specialists, little more than a beginning of the revi-
sion has been made. Mr. Hodge continued to represent the Smith-
sonian Institution at the meetings of the United States Board on
Geographic Names, and the Bureau of American Ethnology on the
Smithsonian advisory committee on printing and publication.

Dr. J. Walter Fewkes, ethnologist, spent the summer months and
part of the autumn of 1912 in correcting the proofs of his monograph
on Casa Grande and of his report on the Antiquities of the Upper
Verde River and Walnut Creek Valleys, Arizona, both of which

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appear in the Twenty-eighth Annual Report of the bureau, and in completing the draft of a memoir devoted to the Symbolic Designs on Hopi Pottery, which it is designed to publish with numerous illustrations. The remainder of the autumn was occupied by Dr. Fewkes in gathering material for an eventual memoir on the Culture History of the Aborigines of the Lesser Antilles, these data being derived chiefly from a study of the early literature of the subject and of the rich West Indian collections from the island of St. Vincent in the Heye Museum of New York City. Preparatory to the publication of the final results, Dr. Fewkes, with the generous permission of George G. Heye, Esq., selected with entire freedom the necessary objects for illustration, and before the close of the fiscal year about 200 drawings of the archeological objects in this important collection had been finished.

In October, 1912, Dr. Fewkes sailed for the West Indies under the joint auspices of the bureau and the Heye Museum, the special object in view being the gathering of new archeological data through the excavation of village sites and refuse-heaps and the examination of local collections in the islands. Dr. Fewkes visited Trinidad, Barbados, St. Vincent, Balliceaux, Grenada, Dominica, St. Kitts, Santa Cruz, and other islands, excavating shell-heaps in Trinidad and Balliceaux, and making archeological studies in other isles. The results of the investigations in Trinidad proved to be especially important, owing to the light which they shed on the material culture of the former aborigines of the coast adjacent to South America.

Extensive excavations were made in a large shell-heap, known as Tchip-Tchip Hill, on the shore of Erin Bay in the Cedros district. This midden is historic, for it was in Erin Bay that Columbus anchored on his third voyage, sending men ashore to fill their casks at the spring or stream near this Indian mound. Tchip-Tchip Hill is now covered with buildings to so great an extent that it was possible to conduct excavations only at its periphery; nevertheless the diggings yielded a rich and unique collection that well illustrates the culture of the natives of this part of Trinidad. The collection consists of several fine unbroken pottery vessels with painted decoration, and more than a hundred well-made effigy heads of clay, in addition to effigy jars and many broken decorated bowls. There were also obtained from the Erin Bay midden several stone hatchets characteristic of Trinidad and the adjacent coast of South America, a few shell and bone gorgets, and other artifacts illustrating the activities of the former inhabitants. It is an interesting fact that as a whole the objects here found resemble those that have been taken from shell-heaps on the Venezuela coast and from the Pomeroon district of British Guiana more closely than they resemble related specimens from the other islands of the Lesser Antilles. Several other middens

were examined in Trinidad, the most representative of which is situated near San Jose, the old Spanish capital. Promising shell-heaps were discovered also at Mayaro Bay on the eastern coast.

One of the most important results of the West Indian field work by Dr. Fewkes was a determination of the geographical distribution of certain types of artifacts and a comparison of the prehistoric culture areas in the so-called Carib Islands. Evidence of the existence of a sedentary culture on these islands preceding that of the Carib was obtained, showing it to have distantly resembled that of Porto Rico; this culture, however, was not uniform. Dr. Fewkes also found that there were a number of subcultures in these islands. In prehistoric time Trinidad and Tobago, it was determined, were somewhat similar culturally, just as they are similar geologically and biologically, to northern South America. In Dr. Fewkes's opinion perhaps nowhere is the effect of environment on human culture better illustrated than in the chain of islands extending from Grenada to Guadeloupe, which were inhabited, when discovered, by Carib, some of whose descendants are still to be found in Dominica and St. Vincent. The earlier or pre-Carib people were culturally distinct from those of Trinidad in the south, St. Kitts in the north, and Barbados in the east. The stone implements of the area are characteristic and the prehistoric pottery can readily be distinguished from that of the islands beyond the limits named.

A large number of shell-heaps on St. Vincent were visited and studies made of localities in that island in which caches of stone implements have been found. Six groups of petroglyphs were examined, even some of the best known of which have never been described. Special effort was made to obtain information respecting the origin of certain problematical objects of tufaceous stone in the Heye Museum, said to have been collected from beneath the lava beds on the flank of the Soufrière.

Dr. Fewkes visited the locality on the island of Balliceaux where the Carib of St. Vincent were settled after the Carib wars and before they were deported to Roatan on the coast of Honduras. Extensive excavations were made at the site of their former settlement at Banana Bay, where there is now a midden overgrown with brush. Here much pottery, as well as several human skeletons and some shells and animal bones, were found.

The mixed-blood survivors of the St. Vincent Carib who once lived at Morne Rond, near the Soufrière, but who are now settled at Campden Park near Kingstown, were visited. These still retain some of their old customs, as making cassava from the poisonous roots of the manihot, and preserve a few words of their native tongue. A brief vocabulary was obtained, but Carib is no longer habitually spoken in St. Vincent.

The fertile island of St. Kitts and the neighboring Nevis were found to be particularly instructive archeologically. Both have several extensive middens and well-preserved pictographs, the former having yielded many artifacts that illustrate the material culture of its pre-Carib inhabitants. Through the courtesy of Mr. Connell his large collection, which adequately illustrates the culture of St. Kitts and Nevis, was placed at the disposal of Dr. Fewkes for the purpose of study, and he was permitted to make drawings of the more typical objects, one of the most instructive of which is a sculptured torso from Nevis.

In Barbados Dr. Fewkes examined the midden at Indian River, on the west coast, from which site the important Taylor archeological collection was gathered. Several other middens were visited on the lee coast from Bridgetown to the northern end of the island, where a marly hill strewn with potsherds was observed. He also examined the so-called "Indian excavations" at Freshwater Bay and others at Indian River, and visited several cave shelters on the island. The most noteworthy of these caves are situated at Mount Gilboa and in the Scotland district, St. Lucy Parish. To one of these, known as the "Indian Castle," described in 1750 by the Rev. Griffith Hughes, who claims to have found therein an idol and other undoubted Indian objects, Dr. Fewkes devoted much attention. The gulches so characteristic of Barbados were favorite resorts of the aborigines, and, judging by the artifacts, furnished cave shelters for them. Although uninhabited at the time of its discovery, there is evidence of a considerable prehistoric aboriginal population in Barbados, whose culture was influenced largely by the character of the material from which their artifacts were made, most of them being fashioned from shell instead of stone, a characteristic seemingly constituting this island a special culture area.

A collection of stone implements, including celts, axes, and other objects, was gathered at Santa Cruz. Several local collections of archeological objects were examined, and the large midden at the mouth of Salt River was visited. The prehistoric objects obtained on this island and from St. Thomas resemble those from Porto Rico.

Although the Carib inhabitants of the Lesser Antilles are no longer of pure blood, and their language is known to only a few persons in Dominica and St. Vincent, and to these but imperfectly, it was found that the negroes, who form more than nine-tenths of the insular population, retain in modified form some traces of the material culture of the Indians. Cassava is the chief food of many of the people, and the method of its preparation has been little changed since aboriginal times. Cocoa is ground on a stone and made into cylindrical rolls in much the same manner as it was prepared by the Indians in early times. The basketry made in Do-

minica was found to be the same in style and materials as is described by the early missionaries to the Carib; while the negroes of Nevis manufacture pottery of the same form and ornament and burn it in much the same way as that found in the middens of St. Kitts. In working their spells, the obia men commonly sprinkle stone objects with the blood of a goat, and the common people regard petroglyphs as "jumbies," or bugaboos. A great number of folk tales of a mixed aboriginal and negro type are still recounted in the cabins of the lowly, where Carib names for animals, plants, and places are household words.

On his return to Washington Dr. Fewkes undertook the preparation of a report on his archeological researches in the West Indies, and considerable progress therein had been made by the close of the fiscal year.

Mr. James Mooney, ethnologist, was occupied during the greater part of the year with the investigation of Indian population, which has engaged his attention for a considerable time. This research covers the whole period from the first occupancy of the country by white people to the present time, and includes the entire territory from the Rio Grande to the Arctic. To make possible systematic treatment the area covered has been mapped into about 25 sections, each of which constitutes approximately a single geographical and historical unit for separate treatment, although numerous migrations and removals, and the frequent formation of new combinations, necessitate a constant overlapping of the work of the sections. Several of the eastern areas have been completed and more or less progress has been made with each of the others. More recently Mr. Mooney has concentrated attention on Alaska and western Canada, for the Arctic parts of which Mr. Vilhjálmur Stefánsson and Dr. Waldemar Jochelson have generously furnished new and valuable data. In this memoir the plan is to include chapters on notable epidemics, vital statistics, and race admixture, and the work is intended to appear as a monograph on the subject.

On June 18, 1913, Mr. Mooney proceeded to the Eastern Cherokee Indians in North Carolina to continue his investigations of the medical and religious ritual of that tribe, commenced a number of years ago, as it was deemed wise to finish this part of his Cherokee studies as soon as practicable by reason of the changes that are so rapidly taking place among this people. Mr. Mooney was still in the field at the close of the fiscal year.

Dr. John R. Swanton, ethnologist, continued, both in the field and at the office, his studies of the Indians formerly occupying the territory of the southern States. He spent the month of November, 1912, with the Alabama and Koasati Indians in Polk County, Tex., where he recorded 250 pages of texts in the dialects spoken by these

two tribes, corrected several texts obtained on earlier expeditions, and added materially to his general ethnological information regarding them. In December Dr. Swanton proceeded to Oklahoma, where he obtained about 50 pages of text in Hitchiti, a language now confined to a very few persons among the Creek Indians, and collected a few notes regarding the Choctaw.

Before his departure from Washington and after his return Dr. Swanton spent the greater part of the time in collecting information concerning the Southern tribes from early Spanish, French, and English authorities. Considerable attention was also devoted to reading the proofs of the Rev. Cyrus Byington's Choctaw Dictionary, now in process of printing, in which labor he was efficiently aided by Mr. H. S. Halbert, of the Alabama State department of archives and history. Dr. Swanton also commenced a general grammatical study of the languages of the Muskhogean stock, particularly Alabama, Hitchiti, and Choctaw, and in order to further this work he was subsequently engaged in making a preliminary stem catalogue of Creek from the material recorded by the late Dr. Gatschet, similar to the catalogue already prepared for Hitchiti, Alabama, and Natchez. He began also the preparation of a card catalogue of words in Timucua, the ancient extinct language of Florida, taken from the grammar and catechisms of Father Pareja. In May, Dr. Swanton visited New York in order to examine rare Timucua works in the Buckingham Smith collection of the New York Historical Society. Through the courtesy of this society and of the New York Public Library arrangements have been made for furnishing photostat copies of these rare and important books, and the reproductions were in preparation at the close of the fiscal year.

In connection with the researches of Dr. Swanton, it is gratifying to report that he was awarded last spring the second Loubat prize in recognition of his two publications—" Tlingit Myths and Texts " and " Indian Tribes of the Lower Mississippi Valley and Adjacent Coast of the Gulf of Mexico "—both issued by the bureau.

Mrs. M. C. Stevenson, ethnologist, devoted her time to the conclusion of her researches among the Tewa Indians of New Mexico and to the preparation of a paper on that interesting and conservative people. A preliminary table of contents of the proposed memoir indicates that her studies of the customs and beliefs of the Tewa will be as comprehensive as the published results of her investigations of the Sia and the Zuñi tribe of the same State. As at present outlined, the work, which will soon be completed, will contain six sections, dealing with the following subjects, respectively: Philosophy, anthropic worship and ritual, zoic worship, social customs, material culture, and history.

Dr. Truman Michelson, ethnologist, continued his studies among the Algonquian tribes. In the middle of July, 1912, he proceeded to the Fox Indians, at Tama, Iowa, from whom a large additional body of mythological material was obtained; this, in connection with the myths and legends in the form of texts gathered during the previous season, approximates 7,000 pages. When the translation of this material shall have been finished it will form one of the most exhaustive collections of mythology of any Indian tribe. It is noteworthy that these myths and tales differ essentially in style from those gathered by the late Dr. William Jones (scarcely any of whose material has been duplicated by Dr. Michelson), a fact that emphasizes the necessity of recording such material in the aboriginal tongue. It may be added that the myths and tales collected are also important in the light they shed on the dissemination of myths. Study of the social and ceremonial organization of the Fox Indians was likewise continued, and especially full notes were obtained on their Religion dance. Many of the songs of one of the drums were recorded on a dictaphone and several photographs of the native ball game were secured.

Dr. Michelson next proceeded to Haskell Institute, the nonreservation Indian school at Lawrence, Kans., for the purpose of obtaining notes on Atsina (Gros Ventre) and several other Algonquian languages, the results of which show definitely that Atsina shares with Arapaho all the deviations from normal Algonquian, and that Potawatomi is further removed from Ojibwa, Ottawa, and Algonkin than any one of these is from the others.

Dr. Michelson next visited the Munsee, in Kansas, but found that, unfortunately, little is now available in the way of information except as to their language, which is still spoken by about half a dozen individuals, though none employ it habitually.

The Delawares of Oklahoma were next visited, Dr. Michelson finding that their aboriginal customs are still retained to a large extent. Extended observations were made on several dances, and, to a lesser extent, on the social organization. From a study of the Delaware language, together with the Munsee dialect of Kansas, it was ascertained, as had previously been surmised, that the Delaware language of the early Moravian missionary Zeisberger represents no single dialect but a medley of several dialects.

On his way to Washington Dr. Michelson stopped again at Tama to obtain additional notes on the Fox Indians; at the same time he succeeded in arranging for the acquirement of certain sacred packs for the National Museum. He also visited Chicago and New York for the purpose of making comparative observations on the material culture of the Fox tribe, based on collections in the museums of those cities.

On his arrival in Washington, at the close of December, Dr. Michelson undertook the translation and study of some of the Fox myths; the results indicate that very great firmness in the word unit in Algonquian is more apparent than real, and that the classification of stems must be revised. Dr. Michelson also brought to conclusion his translation of the Kickapoo myths and tales collected by the late Dr. Jones, to which were added notes on Kickapoo grammar and comparative notes on the myths and tales, the whole making somewhat more than 300 pages.

Through correspondence Dr. Michelson succeeded in arranging for the acquirement of other sacred packs of the Fox Indians, which have been deposited in the National Museum. He also aided in furnishing information in answer to inquiries by various correspondents, and from time to time supplied data for incorporation in a new edition of the Handbook of American Indians.

From the investigations of the bureau it seemed that the Siouan and Muskhogean languages resembled each other morphologically. In view of these circumstances, it was deemed desirable that the Catawba, one of the Siouan tongues, should be restudied, and accordingly, toward the close of May, 1913, Dr. Michelson proceeded to South Carolina, where the remnant of the Catawba tribe still reside. Unfortunately, it was found that the language is all but extinct, not even half a dozen persons being able to recall phrases, although isolated words can still be had in goodly number. Owing to this paucity of text material it is hardly likely that the grammar of Catawba will ever be completely elucidated, and as no comparative study with other Siouan dialects has yet been made, it is not practicable at present to say with which Siouan group the language is most closely associated. A considerable number of native songs are still remembered by the surviving Catawba, nearly all of which Dr. Michelson succeeded in recording by dictaphone.

Mr. J. N. B. Hewitt, ethnologist, was occupied during the year in translating unedited Seneca texts of myths which were collected by himself in 1896 and at other times on the Cattaraugus Reservation in western New York and on the Grand River Reservation in Ontario, Canada. These myths, legends, and tales number 13 in all. In addition, Mr. Hewitt undertook the editing of two Seneca texts—" The Legend of S'hagowē''not'hă', or The Spirit of the Tides," and " The Tale of Doä'danégĕⁿ' and Hotkwisdadegĕⁿ''ă' "—recorded by himself in the form of field notes in 1896 and aggregating 95 typewritten pages. At the close of the fiscal year about one-third of this work was completed. To these texts interlinear translations are to be added for the purpose of aiding in the grammatic study of the Seneca tongue.

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Mr. Hewitt also devoted much time to the collection and preparation of data for answers to correspondents of the bureau, especially with reference to the Iroquoian and Algonquian tribes.

Mr. Francis La Flesche, ethnologist, continued his investigations of the ethnology of the Osage Indians, giving particular attention to their rituals and accompanying songs. He was enabled to record on the dictaphone the songs and fragments of the rituals belonging to the Waxobe degree of the $No^{n'}ho^{n}zhi^{n}ga$ rites, of which, as noted in the last annual report, he has been making a special study. These rituals have been transcribed and, with the 84 songs that have been transcribed in musical notation by Miss Alice C. Fletcher, comprise 66 typewritten pages.

Mr. La Flesche has also been able to record the $No^{n'}zhi^{n}zho^{n}$, or Fasting degree, of the Puma and Black Bear gentes. These two organizations are closely related; they not only use in common the songs and rituals of the $No^{n'}ho^{n}zhi^{n}ga$ rites, but they even go to the extent of exchanging gentile personal names as full recognition of their relationship. The $No^{n'}zhi^{n}zho^{n}$ degree employs 12 rituals and numerous songs, of which latter 81 have been recorded. These songs are divided into two great groups, the first of which is known as "The Seven Songs," having 16 sets, and the second, "The Six Songs," having 17 sets. The Osage texts of these rituals and songs cover 207 pages, about three-fourths of which have been finally typewritten. The 81 songs have been transcribed in musical notation by Miss Fletcher, while the translation of the rituals and the words of the songs is in progress.

In the autumn of 1912 Mr. La Flesche was fortunate in securing in full the $Ni'k'i$ degree of these intricate Osage rites. Hitherto he had been able to obtain only the beginning of this degree, but his informant was finally induced to recite it in its entirety, comprising 1,542 lines. The real title of this degree is $Ni'k'i$ $No^{n}k'o^{n}$, "The Hearing of the Words of the People." In it the genesis of the tribe is given in a story made up of myth, legend, and symbolism, the whole being clearly devised to keep the people ever mindful of the necessity of an orderly and authoritative conduct of war. It goes to show that the principle of war was early recognized by the Osage as the surest means by which not only tribal and individual life might be safeguarded against strange and hostile tribes, but also as the means by which the tranquil enjoyment of game and other natural products of their environment might be won. It is to this coveted tranquillity that the closing lines of many of the rituals refer, invariably likening it to a "serene day." This degree employs ritual almost entirely, there being only 10 songs. The native ritual comprises 57 typewritten pages, of which a large part has been translated.

In the spring of 1913 Mr. La Flesche obtained the Rush Mat Weaving degree of the Puma and Black Bear gentes. Only the " Seven Songs " spoken of before, with various ceremonial forms, are employed in this degree, the " Six Songs " being entirely omitted. The distinguishing features are the ceremonial weaving of the rush mat for the sacred case in which were enshrined the bird and other sacred objects, the renewal of all the articles that make up the sacred bundle, and the ceremonial stitching of the ends of the case. In some respects this is one of the most extraordinary degrees of the Osage that Mr. La Flesche has yet observed, since in its performance there are used 70 brass kettles, 70 red-handled knives, and 70 awls in making the various articles, all of which the votary is obliged to furnish, together with other expensive articles that constitute the fees of the initiator and other officiating $No^{n\prime}ho^nzhi^nga$, as also 70 pieces of choice jerked meat for distribution among the members attending the initiation. Three rituals not used in the other degrees are employed in this, namely, the Green Rush ritual, the Bark ritual, and the Stitching and Cutting ritual. There are 61 pages of Osage text, about half of which have been transcribed.

Mr. La Flesche also obtained the rituals and songs of the Washabe $Athi^n$, " The Carrying of a Dark Object," with full description of the various processions and ceremonial forms. This is a war ceremony, which, although not counted as a degree, is a rite to which the seven degrees lead. The name of this ceremony is derived from the war insignia, which is the charcoal ceremonially prepared from certain sacred trees, and which symbolizes the black marks denoting the birds and animals used to typify strength, courage, and fleetness. Mr. La Flesche's Osage informant regards this as the final act of the seven degrees. The Osage text comprises 90 pages, nearly one-half of which has been transcribed, together with 36 songs, which have been transcribed by Miss Fletcher, and 7 diagrams.

Mr. La Flesche was fortunate enough to procure the sacred bundle of the Deer gens and the reed-whistle bundle of the Wind gens; the contents of the latter are of exceptional interest. Mrs. Brogahige, one of the ceremonial weavers of the Osage, at considerable sacrifice to herself, presented Mr. La Flesche two sacred looms, one of which is used in weaving the buffalo-hair case, and the other in weaving the rush case for the sacred bird. These packs, together with specimens of ceremonially made burden straps which Mr. La Flesche collected, have been placed in the National Museum.

Dr. Franz Boas, honorary philologist, continued the preparation of the material for the Handbook of American Indian Languages. As stated in the last annual report, the manuscript of the grammar of the Chukchee language, to appear in Part 2 of this handbook, was completed and in its final form was discussed with the author, Mr.

Waldemar Bogoras, during the visit of Dr. Boas to Berlin in the summer of 1912. The results of these discussions were embodied in the work, the manuscript was delivered, and the typesetting commenced. At the same time Dr. Boas studied the Koryak texts collected by Mr. Bogoras, published in accordance with the plan previously outlined, at the expense of the American Ethnological Society, and the indispensable references were embodied in the grammatical sketch.

The Coos grammar by Dr. Leo J. Frachtenberg was completed, so far as the work of the editor, Dr. Boas, is concerned, the page proofs having been finally revised.

The manuscript for the Siuslaw grammar, also by Dr. Frachtenberg, was submitted and the editing considerably advanced; this will be completed as soon as the entire series of Siuslaw texts are in print, a work that has been undertaken under Dr. Boas's editorship by Columbia University. All the collected texts are now in type, so that examples can be added to the manuscript of the grammar.

Dr. Frachtenberg remained in Siletz, Oreg., throughout the year for the purpose of revising on the spot the materials on the Oregon languages. He was engaged in collecting and arranging the Alsea material for Part 2 of the Handbook of Languages, and in preparing for the discussion of his Molala linguistics. The rapid disappearance of the Calapooya may make it necessary, however, to complete the field work on the language of this people before closing the work on the other manuscripts, even though this procedure may entail delay in the printing of the volume.

Dr. Alexander F. Chamberlain, of Clark University, who has undertaken the preparation of a grammar of the Kutenai language, expects to deliver his manuscript early in the new fiscal year. The printing of this sketch must necessarily be delayed until the text material is available in print.

Miss Haessler continued her preparations for a careful revision of the Dakota Dictionary by Riggs, a work made necessary by reason of the need of greater precision in phonetics and translation, as well as of a more systematic arrangement of the material. Miss Haessler expects to complete all the preliminary work by the summer of 1914, so that, should facilities be available, she will then be able to undertake the required field work.

Miss Frances Densmore continued her studies in Indian music, devoting special attention to that of the Sioux, and during the year submitted three papers, comprising 252 pages of manuscript, original phonographic records and musical transcription of 107 songs, and 23 original photographic illustrations. Three subjects have been exhaustively studied and a fourth is represented in such manner that the results may be regarded as ready for publication. The three

principal subjects are: The sacred stones, dreams about animals, and the buffalo hunt. The fourth subject referred to relates to the warpath and is represented by about 20 songs, but it awaits further study of the military societies. A special group of songs consists of those which have been composed and sung by the Sioux in honor of Miss Densmore.

A study of the music of the Mandan and Hidatsa at Fort Berthold, N. Dak., was made by Miss Densmore in the summer of 1912, in cooperation with the Historical Society of the State of North Dakota. The results of this investigation consist of a manuscript of about 50 pages, with transcriptions of 40 songs.

Miss Densmore also read the proofs of Bulletin 53 (Chippewa Music—II), which is now in press.

Mr. W. H. Holmes, head curator of the department of anthropology of the United States National Museum, continued the preparation of the Handbook of American Archeology for publication by the bureau, as far as the limited time available for the purpose permitted. Aside from the preparation of the text and illustrations for parts 1 and 2 of this handbook, Mr. Holmes made field observations among the ancient mica mines in western North Carolina and among mounds and village sites in South Carolina and Georgia. He also visited a number of museums for the purpose of examining the collections of archeological material, among them being the museums of Boston, Andover, New York City, Philadelphia, Columbus, Chicago, Milwaukee, Madison, Davenport, and St. Louis.

Mr. D. I. Bushnell, jr., made good progress in the compilation of the Handbook of Aboriginal Remains East of the Mississippi, the manuscript material for which, recorded on cards, now approximates 160,000 words. The collated material has been derived from (1) replies to circular letters addressed to county clerks in all of the States east of the Mississippi, (2) communications from various societies and individuals, and (3) publications pertaining to the subject of American antiquities. It is gratifying to state that there are very few areas not covered by the material already in hand, and it is expected that through the systematic manner in which Mr. Bushnell is prosecuting the work the handbook will be as complete as it is practicable to make it by the time it is ready for publication.

The investigations conducted jointly in 1910 and 1911 by the bureau and the School of American Archæology have borne additional fruit. An extended memoir on the Ethnogeography of the Tewa Indians, by J. P. Harrington, was received and will appear as the " accompanying paper " of the Twenty-ninth Annual Report, now in press. Three bulletins, namely, (No. 54) The Physiography of the Rio Grande Valley, New Mexico, in Relation to Pueblo Culture,

by Edgar L. Hewett, Junius Henderson, and W. W. Robbins; (No. 55) The Ethnobotany of the Tewa Indians, by Barbara W. Freire-Marreco, W. W. Robbins, and J. P. Harrington; and (No. 56) The Ethnozoology of the Tewa Indians, by Junius Henderson and J. P. Harrington, were also presented as a part of the results of the joint expeditions and are either published or in process of printing. Mr. Harrington also made progress in the preparation of his report on the Mohave Indians, and Miss Freire-Marreco is expected to submit shortly an extended paper on the Yavapai tribe. There remains to be mentioned in this connection another memoir, namely, An Introduction to the Study of the Maya Hieroglyphs, by Sylvanus G. Morley; while not a direct product of the joint work of the bureau and the school, this is in a measure an outgrowth of it. The manuscript, together with the accompanying illustrations, has been submitted to the bureau, but is now temporarily in the author's hands for slight revision.

Since the publication of the Handbook of American Indians, through which additional popular interest in our aborigines has been aroused, it has been the desire to make a beginning toward the preparation of a series of handbooks devoted to the Indians of the respective States. The opportunity was fortunately presented toward the close of the fiscal year, when the bureau was enabled to enlist the aid of Dr. A. L. Kroeber, of the University of California, who has kindly consented to undertake the preparation of the initial volume of the series, to be devoted to the Indians of California. It is planned to present the material in each volume in as popular a form as practicable, in order that it may be made of the greatest use to schools, and it is hoped that the means may be soon available to make possible the extension of the series to other States.

Under a small allotment from the bureau, Mr. James Murie continued his studies of Pawnee ceremonies. He devoted special attention to the medicine rites, and on June 13, 1913, submitted a description of the ritual pertaining to the "Purification of the Buffalo Skull".

The transcription of the manuscript French-Miami Dictionary in the John Carter Brown Library at Providence, R. I., to which attention has been directed in previous reports, was finished by Miss Margaret Bingham Stillwell, who submitted the last pages of the vocabulary (which number 1,120 in all) early in January, 1913. The bureau is under obligations to Mr. George Parker Winship, librarian of the John Carter Brown Library, for his generous cooperation in placing this valued document at the disposal of the bureau and to Miss Stillwell for the efficient manner in which this difficult task was accomplished.

In the latter part of the fiscal year Mr. Jacob P. Dunn, of Indianapolis, in whose hands the French-Miami Dictionary was placed for study, commenced the annotation of the transcription and the addition of English equivalents. This necessitated a journey to Oklahoma, where Mr. Dunn enlisted the services of a Miami Indian as an interpreter. The result of these studies consists of (*a*) the French-Miami-English Dictionary, from *Abbaiser* to *Cajeux;* (*b*) The History of Genesis, Chapter I, being Peoria text with Miami-English translation; (*c*) English-Miami Dictionary, from *Abandon* to *Aim;* (*d*) Wissakatcakwa Stories, recorded in Peoria by the late Dr. Gatschet, for which Mr. Dunn has made an interlinear translation.

The compilation of the List of Works Relating to Hawaii was continued by Prof. Howard M. Ballou, of the College of Hawaii, who from time to time has submitted additional titles. The recording of the material by more than one person necessarily resulted in more or less inconsistency in form; consequently the manuscript, which consists of many thousands of cards, has been in need of editorial revision in order to insure uniformity. For this revision the bureau has been fortunate in enlisting the services of Mr. Felix Neumann, an experienced bibliographer, who is making progress in the work.

PUBLICATIONS.

The editorial work of the bureau has been conducted as usual by Mr. J. G. Gurley, editor. The following publications were issued during the year:

Twenty-eighth Annual Report, containing " accompanying papers " as follows: (1) Casa Grande, by Jesse Walter Fewkes; (2) Antiquities of the Upper Verde River and Walnut Creek Valleys, Arizona, by Jesse Walter Fewkes; (3) Preliminary Report on the Linguistic Classification of Algonquian Tribes, by Truman Michelson.

Bulletin 30, Handbook of American Indians North of Mexico, edited by Frederick Webb Hodge. By concurrent resolution of Congress, in August, 1912, a reprint of this bulletin was ordered in an edition of 6,500 copies, of which 4,000 were for the use of the House of Representatives, 2,000 for the use of the Senate, and 500 for the use of the bureau. This reprint, in which were incorporated such desirable alterations as could be conveniently made without affecting the pagination of the work, was issued in January, 1913.

Bulletin 52, Early Man in South America, by Aleš Hrdlička, in collaboration with William H. Holmes, Bailey Willis, Fred. Eugene Wright, and Clarence N. Fenner.

Bulletin 54, The Physiography of the Rio Grande Valley, New Mexico, in Relation to Pueblo Culture, by Edgar Lee Hewett, Junius Henderson, and Wilfred William Robbins.

The work on the other publications during the year may be summarized as follows:

Twenty-ninth Annual Report (" accompanying paper," The Ethnogeography of the Tewa Indians, by John Peabody Harrington). Manuscript prepared for the printers and nearly half of the composition finished.

Thirtieth Annual Report (" accompanying papers ": (1) Animism and Folklore of the Guiana Indians, by Walter E. Roth; (2) Tsimshian Mythology, by Franz Boas; (3) Ethnobotany of the Zuñi Indians, by Matilda Coxe Stevenson). Editing of the third paper and to a considerable extent that of the first paper completed.

Bulletin 40, Handbook of American Indian Languages, by Franz Boas—Part 2. Work on the Coos section nearly finished and composition of the Chukchee section begun. Two sections (Takelma and Coos) are now " made up," aggregating 429 pages.

Bulletin 46, A Dictionary of the Choctaw Language, by Cyrus Byington, edited by John R. Swanton and H. S. Halbert. The editors have revised two galley proofs of the Choctaw-English section of this dictionary and have practically finished preparation for the printers of the English-Choctaw section. The first part of this bulletin is now in process of paging.

Bulletin 53, Chippewa Music—II, by Frances Densmore. Manuscript edited and the several proofs read, including proofs of 180 pieces of music. At the end of the year the bulletin was held in the Printing Office awaiting receipt of the necessary paper stock.

Bulletin 55, Ethnobotany of the Tewa Indians, by Barbara Whitchurch Freire-Marreco, Wilfred William Robbins, and John Peabody Harrington. Manuscript edited and the work in galley form at the close of the year.

Bulletin 56, Ethnozoology of the Tewa Indians, by Junius Henderson and John Peabody Harrington. Manuscript edited and the work in page form at the close of the year.

In accordance with the act of Congress approved August 23, 1912, the entire stock of publications of the bureau, with the exception of a few copies of each available work which have been retained at the Smithsonian Institution for special purposes, was transferred to the Government Printing Office in October, 1912, for distribution from the office of the superintendent of documents on order from the bureau. It has been found that this plan of distribution is highly successful, and, of course, much less expensive to the bureau.

The correspondence relating to publications, of which 15,070 were distributed during the year, was conducted under the immediate supervision of Miss Helen Munroe, of the Smithsonian Institution. The distribution of the publications may be summarized as follows:

Series:

	Copies.
Report volumes and separate papers	3, 895
Bulletins	11, 040
Contributions to North American Ethnology	15
Introductions	7
Miscellaneous publications	113
	15, 070

The demand for the Handbook of American Indians (Bulletin 30) continues unabated, by reason of the wide scope of the work, its popular form of treatment, and its usefulness to schools. There is an increasing demand for publications relating to Indian arts and crafts, and to archeology. The activity in the establishment of organizations of Camp Fire Girls throughout the country has resulted in a flood of requests for information relative to Indian customs, names, etc.

ILLUSTRATIONS.

As in the past, the preparation of illustrations for use in connection with the publications of the bureau, as well as the making of photographic portraits of the members of visiting deputations of Indians, continued in the immediate charge of Mr. De Lancey Gill, illustrator, whose work during the year included the making of negatives of 113 visiting Indians and of 93 miscellaneous ethnologic subjects; he also developed 298 negatives exposed by members of the bureau in their field work, printed 975 photographs for official publication, exchange, and presentation to Indians, and prepared 105 drawings for reproduction as illustrations for the publications of the bureau.

The tribes or pueblos represented by Indians who visited Washington during the year are: Acoma, Apache, Cheyenne, Chippewa, Cochiti, Crow, Isleta, Kiowa, Osage, Passamaquoddy, Ponca, San Juan, Santa Clara, Shoshoni, Sioux, Taos, and Wichita. Among the more important Indians whose portraits were made may be mentioned Plenty Coups and Medicine Crow (Crow tribe), Big Man and Iron Bear (Brulé Sioux), Hollow Horn Bear, Red Cloud, and Red Hawk (Teton Sioux), Daybwawaindung (Chippewa), and Two Moons (Cheyenne). Many requests are made by correspondents for prints from the large collection of negatives in possession of the bureau, but it has not been possible to supply these, owing to lack of means, although in many cases they are desired for educational purposes. The series of photographs of representative Indians, from 55 tribes, which was made during the last fiscal year for special exhibition at the New York Public Library, has been borrowed from the bureau by the Public Library Commission of Indiana for exhibition in the public libraries throughout the State. In the work of the photographic laboratory Mr. Gill was assisted by Mr. Walter J. Stenhouse.

LIBRARY.

The library of the bureau continued in immediate charge of Miss Ella Leary, librarian, assisted by Mrs. Ella Slaughter. During the year the accessions comprised 562 volumes (of which 129 were purchased) and 244 pamphlets, bringing the total number of volumes in the library to 18,532, and the pamphlets to 12,744. The periodicals currently received by the bureau, of which there are several thousand unbound parts, number 629; of these all but 18 are obtained in exchange for the bureau's publications. Special attention was paid during the year to filling lacunæ in the periodical series.

The cataloguing kept apace with the new accessions, and some progress was made in cataloguing ethnologic and related articles in the earlier serials. A monthly bulletin for the use of the members of the bureau staff was compiled and posted by the librarian, who also made a beginning in the preparation of a list of writings on the music of American Indians.

As in the past, it was necessary to draw on the collections of the Library of Congress, about 300 volumes having been borrowed during the year. On the other hand, the library of the bureau is frequently consulted by officers of the departments of the Government, as well as by students not connected with the Smithsonian Institution.

While many volumes are still without binding, the condition of the library in this respect has greatly improved during the last few years; 493 volumes were bound at the Government Printing Office during the year.

COLLECTIONS.

The following collections were made by the bureau or by members of its staff during the fiscal year and transferred to the National Museum:

54311. Six photographs (unmounted) taken by A. J. Horswill, San Jose, Mindoro, P. I., among the natives of Mindoro Island. Gift to the bureau by Munn & Co., New York.

54465. Sacred pack of the Fox Indians of Iowa. Purchased for the bureau by Dr. Truman Michelson.

54691. Five pieces of cotton painted with Assyrian subjects. Received by the bureau from an unknown source.

54798. Three sacred looms and seven burden straps of the Osage Indians. Collected by Francis La Flesche.

54933. Three fragments of Indian pottery found at Red Willow, Nebr., by Mrs. Ada Buck Martin, by whom they were presented.

54934. Sacred bundle of the Fox Indians. Purchased through Dr. Truman Michelson.

54946. Two sacred bundles of the Osage Indians. Purchased by Francis La Flesche.

55002. Sacred bundle of the Fox Indians. Purchased through Dr. Truman Michelson.

55075. An Osage buffalo-hair rope (reata) and an Osage woven belt. Purchased through Francis La Flesche.

55234. Two ethnological objects from the natives of British Guiana, presented to the bureau by Dr. Walter E. Roth, of Pomeroon River, British Guiana.

55323. Set of five plum-seed gaming dice of the Omaha Indians and a bottle of seeds used by the same Indians as perfume. Presented by Francis La Flesche.

55420. Pair of Osage ceremonial moccasins and an Osage ceremonial "pipe." Presented by Francis La Flesche.

PROPERTY.

As stated in previous reports, the property of the bureau of greatest value consists of its library, manuscripts for reference or publication, and photographic negatives. A reasonable number of cameras, dictagraphs, and other apparatus, chiefly for use in the field, as well as a limited stock of stationery and office supplies, necessary office furniture, and equipment, are also in possession of the bureau. The sum of $893.21 was expended for office furniture (including fireproof filing cases) during the year, $452.57 for apparatus (including typewriters, cameras, dictagraphs, etc.), and $258.45 for books and periodicals.

The manuscripts of the bureau, many of which are of extreme value, are deposited in metal cases in a small room in the north tower of the Smithsonian Building, which should be made as nearly fireproof as possible. Requests for a small appropriation to protect the manuscripts against possible destruction have been made in the past, but unfortunately the means have not been granted. The manuscripts, which have been in the immediate care of Mr. J. N. B. Hewitt, have increased from time to time during the year, chiefly by the temporary deposit of materials preparatory to editing for publication. Mention may here be made, however, of the gift of some manuscript Chippewa letters from the Rev. Joseph A. Gilfillan, and the acquirement of a photostat copy of the Motul-Maya Dictionary, made at the expense of the bureau from the original in the John Carter Brown Library, at Providence, R. I., as elsewhere noted. Mention may also be made of various vocabularies or parts of vocabularies, 23 items in all, which were restored to the bureau by Mrs. Louisa H. Gatschet, who found them among Dr. Gatschet's effects.

MISCELLANEOUS.

Quarters.—Since the beginning of 1910 the offices of the bureau have occupied nine rooms in the north tower of the Smithsonian Building, and a room (the office of the ethnologist-in-charge) on the north side of the third floor of the eastern wing, while the library

has occupied the entire eastern gallery of the large exhibition hall on the first floor, and the photographic laboratory part of the gallery in the southeastern section of the old National Museum building. While the natural lighting of the rooms in the north tower, by reason of the thickness of the walls and the narrowness of the windows, is inadequate, and the distance from the library and the photographic laboratory makes them not readily accessible, the office facilities are far better than when the bureau was housed in cramped rented quarters. Aside from the photographic laboratory and one room in the north tower, no part of the bureau's quarters is provided with running water. It is presumed that after the rearrangement of the large exhibition hall in the Smithsonian building and its adaptation to general library purposes the facilities of the bureau library will be greatly improved.

Office force.—The office force of the bureau has not been augmented, although the correspondence has greatly increased owing to the growing demand on the bureau for information respecting the Indians. The copying of the rough manuscripts, field notes, etc., prepared by members of the bureau, as well as the verification of quotations, bibliographic citations, and similar work of a minor editorial nature, necessitate the employment of temporary aid from time to time. Most of the answers to correspondents who desire information of a special character have been prepared by the ethnologist-in-charge, but every member of the bureau's scientific staff is frequently called on for the same purpose to furnish information pertaining to his particular field of knowledge.

RECOMMENDATIONS.

It is difficult to extend the systematic researches of the bureau along new and necessary lines without an increase of appropriations. When a special research is undertaken, several years are often required to finish it, consequently the prospective income of the bureau for a considerable period is required to carry out adequately the work in hand. Opportunities are often presented for conducting investigations in new fields which have to be neglected owing to lack of means. An increase in the appropriations of the bureau has been urged for several years, but unfortunately the estimates have not been met with additional funds.

Respectfully submitted.

F. W. HODGE,
Ethnologist-in-charge.

Dr. CHARLES D. WALCOTT,
Secretary of the Smithsonian Institution,
Washington, D. C.

APPENDIX 3.

REPORT ON THE INTERNATIONAL EXCHANGES.

SIR: I have the honor to submit the following report on the operations of the International Exchange Service during the fiscal year ending June 30, 1913.

The appropriation made by Congress for the support of the service during the year, including the allotment for printing and binding, was $32,200 (the same amount as appropriated for the past five years), and the repayments from private and departmental sources for services rendered aggregated $4,249.13, making the total available resources for carrying on the system of international exchanges $36,449.13.

The work of the service is increasing at such a rapid rate that it will be necessary in the near future to ask Congress to supply additional funds. More money is needed to meet freight charges on the increased number of boxes now shipped abroad, and also for miscellaneous incidental expenses incurred in connection with the work of the service. In 1913, 66 per cent more packages were handled than in 1908, when the appropriation was first placed at $32,200, and 678 more boxes were dispatched. By means of various economies and improvements in methods this increase in the volume of business has been provided for without adding to the total cost of the service; but little more can be done in this direction.

During the year 1913 the total number of packages handled was 338,621, an increase of 23,129, as compared with the preceding year. The weight of these packages was 593,969 pounds, an increase of 25,257 pounds.

The number and weight of the packages of different classes are indicated in the following table:

Number and weight of packages sent and received.

	Packages.		Weight.	
	Sent.	Received.	Sent.	Received.
			Pounds.	*Pounds.*
United States parliamentary documents sent abroad.........	140,345	....	103,820	....
Publications received in return for parliamentary documents..	....	2,085	....	11,780
United States departmental documents sent abroad.........	78,937	....	173,962	....
Publications received in return for departmental documents..	....	9,923	....	18,847
Miscellaneous scientific and literary publications sent abroad..	62,446	....	158,227	....
Miscellaneous scientific and literary publications received from abroad for distribution in the United States..........	....	44,885	....	127,333
Total..	281,728	56,893	436,009	157,960
Grand total.......................................	338,621		593,969	

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As was somewhat fully explained in last year's report, the disparity between the number of packages dispatched and those received in behalf of the Government is not so great as indicated by these figures.   Packages sent abroad usually contain only a single publication each, while those received in return often comprise many volumes.   In the case of publications received in exchange for parliamentary documents and some others the term " package " is applied to large boxes containing a hundred or more publications.   No lists of these are made in the Exchange Office, as the boxes are forwarded to their destinations unopened.   It is also a fact that many returns for publications sent abroad reach their destinations direct by mail and not through the Exchange Service.

Many governmental and scientific establishments and individuals, both in this country and abroad, have sought the aid of the International Exchange Service during the year in procuring, as gifts or exchanges, certain especially desired publications.   The correspondence which this work entails upon the Exchange Service is considerable and is growing in volume from year to year.   Sometimes information collected by this Government, but not to be found in published reports, is requested.   In these instances the various governmental bureaus furnish the desired data in typewritten form.   As an example of a request of this kind received during the year, a case may be mentioned in which valuable statistics concerning blister copper were supplied by the Bureau of the Census and the Bureau of Mines for transmission to the high commissioner of the Commonwealth of Australia for the use of his home Government.   Another request of this character which was complied with was one received through the Department of State from the minister of public works and mines of New Zealand for publications containing the laws and regulations with respect to the boring, mining, and storage of petroleum in the United States.   In this instance, while the Bureau of Mines was in a position to furnish information on the mining of petroleum on Indian reservations, it was necessary for the Institution to write to the principal States having laws on the subject in question in order to obtain the desired data.   It may, however, be added in this connection that the Bureau of Mines is engaged in collecting, arranging, and annotating all the laws, both National and State, relating to all branches of mining, including the petroleum industry, and that a copy of this work, when issued, will be furnished the Institution for presentation to the minister of public works.

The Department of State, in referring a communication from the librarian of the Brazilian Press Association at Rio de Janeiro requesting aid in the establishment of a library in that city to be composed entirely of the works of American writers, stated that while the department itself had no facilities for obtaining such publications it

PLATE 1.

Smithsonian Report, 1913.—Secretary's Report.

PHOTOGRAPH OF PORTION OF 2,000 PACKAGES OF THE PROCEEDINGS OF THE EIGHTH INTERNATIONAL CONGRESS OF APPLIED CHEMISTRY RECEIVED BY THE EXCHANGE SERVICE FOR DISTRIBUTION ABROAD.

was naturally interested in having the more important works of American writers, as well as the governmental documents containing statistical information, placed within easy reach of our neighbors in the Latin-American countries, and that it would be gratifying to the department if the Smithsonian Institution should find it practicable to send to the association such works and statistics regarding science, literature, agriculture, industry, commerce, etc., as might seem suitable. The desire of the Brazilian Press Association was brought to the attention of certain governmental establishments and also of many scientific and literary organizations throughout the United States. The majority of these organizations gave the matter favorable attention, some of them sending complete sets of their publications and adding the name of the American library to their lists to receive future issues. The Smithsonian Institution, I need hardly add, contributed a selection of its own publications. Altogether, more than 1,200 publications were received and transmitted to the Brazilian Press Association through the International Exchange Service as a nucleus for the proposed library.

The chief of the bureau of publications of the Department of Agriculture and Forestry, Peking, China, while attending the Seventeenth International Dry Farming Congress as a delegate from his Government, forwarded to this Institution, for distribution among the various State agricultural experiment stations, a number of copies of three issues of an agricultural journal published by his bureau, with the request that such bulletins as the experiment stations might issue from time to time be sent to his bureau in exchange. This matter was brought to the attention of the various stations, most of which complied with the request by sending copies of their bulletins and listing the name of the Chinese Department of Agriculture to receive their publications regularly in the future.

Many requests for documents are received through the various exchange bureaus abroad, whose services are made use of by this Institution in procuring foreign publications for correspondents in this country. In this connection it may be mentioned that the Government of India invariably requires that requests from establishments in this country for any extended series of Indian official documents be made through the Exchange Service. In such instances the status of the society or establishment making the request is looked into, and statistics and other information relative thereto are furnished the Government of India with a recommendation, when deemed advisable, that the desired documents be furnished.

The foregoing are only a few of the important instances in which the Institution has aided foreign establishments in obtaining publications, in pursuance of a policy of international helpfulness, which

is of benefit to the larger intellectual and economic interests of both the United States and foreign countries. Many other requests of similar nature have been received from correspondents in this country and abroad.

The Institution continues to assist the Library of Congress in completing its collections of foreign governmental documents.

Mention was made last year of the fact that packages containing scientific and literary publications received from establishments and individuals in the United States for transmission through the Exchange Service to miscellaneous addresses in the various Provinces of the Union of South Africa were forwarded to certain governmental establishments in those Provinces for distribution, and that the Government of the Union had been approached with a view to having only one agency for the entire Union. It is now gratifying to state that this request has been complied with, the Government Printing Works at Pretoria having been designated to carry on the exchange work. Packages received in the future for addresses in any of the Provinces of the Union will therefore be transmitted to the Government Printing Works for distribution. This change will effect a saving to the Institution in freight charges, and will also, I have no doubt, improve the service with South Africa. If a similar arrangement could be made with the Commonwealth of Australia it would have decided advantages over the present method of forwarding consignments to six different addresses in that Commonwealth for distribution. The matter is now being considered by the Speaker of the House of Representatives of the Commonwealth of Australia, who is also chairman of the library committee. The Institution has brought to the attention of that official the advantages to be derived from having one central exchange agency in Australia and has urged him to use his best endeavors to have the matter favorably considered by his Government.

The Egyptian Exchange Agency has been transferred from the Egyptian Survey Department to the newly formed Government Publications Department, consignments for distribution in that country now being forwarded in care of the Superintendent of the Government Publications Office, Printing Department, Cairo. It should be stated as a matter of record in this connection that the businesslike basis upon which the exchange service between Egypt and the United States has been placed during the Survey Department's five years' connection therewith has resulted in the prompt delivery of packages to correspondents in both countries.

A circular was received during the year from the Republic of Mexico, stating that a Service of Exchanges had been established in the Department of Public Works.

Of the 2,587 boxes used in forwarding exchanges to foreign bureaus and agencies for distribution (an increase of 192 over 1912), 386 boxes contained full sets of United States official documents for authorized depositories, and 2,201 were filled with departmental and other publications for depositories of partial sets and for miscellaneous correspondents. The number of boxes sent to each foreign country and the dates of transmission are shown in the following table:

Consignments of exchanges for foreign countries.

Country.	Number of boxes.	Date of transmission.
ARGENTINA	43	July 24, Aug. 24, Sept. 25, Oct. 23, Nov. 25, 1912; Jan. 18, Feb. 26, Apr. 3, June 4, 20, 1913.
AUSTRIA	99	July 10, Aug. 7, Sept. 11, Oct. 9, Dec. 11, 1912; Jan. 8, Feb. 5, Mar. 12, Apr. 9, May 14, June 11, 20, 1913.
BELGIUM	77	July 6, 27, Aug. 17, 31, Sept. 20, Oct. 12, Nov. 15, Dec. 7, 1912; Jan. 11, Feb. 1, Mar. 8, 29, Apr. 12, May 3, June 7, 28, 1913.
BOLIVIA	5	Aug. 28, Nov. 30, 1912; Feb. 27, Apr. 3, June 9, 1913.
BRAZIL	42	July 24, Aug. 24, Sept. 25, Oct. 23, Nov. 25, Dec. 19, 1912; Jan. 16, Feb. 26, Apr. 3, June 5, 20, 1913.
BRITISH COLONIES	17	July 6, 13, Aug. 3, 10, 17, Sept. 7, 21, Nov. 16, 1912; Feb. 8, 15, Mar. 22, 29, Apr. 18, May 2, 24, June 6, 27, 1913.
BRITISH GUIANA	5	Sept. 19, Oct. 31, 1912; Jan. 22, Feb. 28, June 16, 1913.
BULGARIA	6	Jan. 6, Feb. 27, Apr. 5, June 10, 1913.
CANADA	7	July 30, Aug. 31, Dec. 2, 1912; Feb. 1, Mar. 13, May 5, June 20, 1913.
CHILE	28	July 24, Aug. 24, Sept. 25, Nov. 25, 1912; Jan. 18, Feb. 26, Apr. 3, June 5, 20, 1913.
CHINA	18	July 30, 31, Aug. 31, Sept. 19, Nov. 8, Dec. 2, 13, 1912; Jan. 3, 29, Feb. 1, Mar. 1, 6, 13, Apr. 29, May 5, June 10, 20, 1913.
COLOMBIA	20	Aug. 28, Oct. 23, Nov. 30, 1912; Jan. 18, Feb. 26, Apr. 3, June 9, 20, 1913.
COSTA RICA	16	July 24, Aug. 28, Sept. 26, Nov. 30, 1912; Jan. 18, Feb. 26, Apr. 3, June 9, 20, 1913.
CUBA	7	July 30, Aug. 31, Dec. 2, 1912; Feb. 1, Mar. 13, May 5, June 20, 1913.
DENMARK	35	July 20, Aug. 15, Sept. 19, Oct. 17, Nov. 18, Dec. 12, 1912; Jan. 16, Feb. 14, Mar. 20, Apr. 15, May 21, June 24, 1913.
ECUADOR	6	Aug. 28, Nov. 30, 1912; Jan. 29, Feb. 27, May 1, June 9, 1913.
EGYPT	13	Aug. 10, Sept. 14, Oct. 12, Nov. 23, Dec. 28, 1912; Feb. 8, Mar. 22, Apr. 22, May 31, June 25, 1913.
FRANCE	230	July 11, 25, Aug. 15, 29, Sept. 19, Oct. 3, 24, Nov. 13, Dec. 5, 26, 1912; Jan. 16, 30, Feb. 13, Mar. 6, 27, Apr. 10, 24, May 22, June 19, 20, 1913.
GERMANY	422	July 2, 9, 16, 23, 30, Aug. 6, 13, 20, 27, Sept. 3, 10, 17, 24, Oct. 1, 8, 15, 22, 29, Nov. 7, 19, 26, Dec. 3, 10, 17, 24, 1912; Jan. 7, 14, 21, 28, Feb. 4, 11, 19, 25, Mar. 11, 18, 25, Apr. 1, 8, 15, 22, 29, May 6, 13, 20, 27, June 3, 10, 17, 24, 1913.
GREAT BRITAIN AND IRELAND.	439	July 6, 13, 20, 27, Aug. 3, 10, 17, 24, 31, Sept. 7, 14, 21, 28, Oct. 5, 12, 19, 26, Nov. 5, 9, 16, 23, 30, Dec. 7, 14, 21, 1912; Jan. 4, 11, 18, 25, Feb. 1, 8, 15, 21, Mar. 1, 8, 15, 22, 29, Apr. 4, 11, 18, 25, May 2, 9, 16, 24, 31, June 6, 14, 21, 27, 1913.
GREECE	19	Aug. 31, Oct. 31, 1912; Jan. 3, Feb. 27, Apr. 5, June 18, 20, 1913.
GUATEMALA	6	Aug. 28, Nov. 30, 1912; Jan. 29, Feb. 27, May 1, June 9, 1913.
HAITI	7	July 30, Sept. 26, 1912; Jan. 3, Feb. 26, Apr. 3, June 7, 20, 1913.
HONDURAS	6	Aug. 28, Nov. 30, 1912; Jan. 29, Feb. 27, May 1, June 9, 1913.
HUNGARY	45	July 10, Aug. 7, Sept. 11, Oct. 9, Nov. 20, Dec. 11, 1912; Jan. 8, Feb. 5, Mar. 12, Apr. 9, May 14, June 11, 20, 1913.
INDIA	46	July 6, 13, 20, 27, Aug. 3, 10, 17, 24, 31, Sept. 7, 14, 21, 26, Oct. 5, 12, 26, Nov. 16, 30, Dec. 7, 14, 1912; Jan. 4, 18, 25, Feb. 8, 15, Mar. 1, 22, 29, Apr. 11, May 24, June 6, 27, 1913.

Consignments of exchanges for foreign countries—Continued.

Country.	Number of boxes.	Date of transmission.
ITALY	107	July 1, Aug. 10, Sept. 12, Oct. 12, Nov. 25, Dec. 28, 1912; Feb. 8, Mar. 22, Apr. 22, May 31, June 25, 1913.
JAMAICA	6	Sept. 17, Nov. 30, 1912; Jan. 30, Feb. 28, May 1, June 16, 1913.
JAPAN	61	July 20, Aug. 23, Sept. 20, Oct. 17, Nov. 25, Dec. 20, 1912; Jan. 21, Feb. 20, Mar. 20, Apr. 17, June 20, 1913.
KOREA	5	Sept. 17, Nov. 30, 1912; Feb. 28, May 1, June 28, 1913.
LIBERIA	5	Sept. 18, Nov. 30, 1912; Feb. 28, May 1, June 16, 1913.
LOURENÇO MARQUEZ	2	Feb. 27, June 28, 1913.
MANITOBA	7	July 30, Aug. 31, Dec. 2, 1912; Feb. 1, Mar. 13, May 5, June 20, 1913.
MEXICO	7	July 30, Aug. 31, Dec. 2, 1912; Feb. 1, Mar. 13, May 5, June 20, 1913.
MONTENEGRO	2	Feb. 27, June 30, 1913.
NETHERLANDS	53	July 9, 30, Aug. 13, 27, Sept. 10, Oct. 8, Nov. 18, Dec. 10, 1912; Jan. 14, 29, Feb. 11, Mar. 11, 25, Apr. 8, May 6, 27, June 17, 20, 1913.
NEWFOUNDLAND	3	July 31, 1912; Mar. 29, June 30, 1913.
NEW SOUTH WALES	31	July 25, Aug. 21, Sept. 24, Oct. 17, Nov. 23, 1912; Jan. 15, Feb. 20, Mar. 26, Apr. 16, May 26, June 23, 1913.
NEW ZEALAND	28	July 25, Aug. 21, Sept. 24, Oct. 18, Nov. 23, 1912; Jan. 15, 23, Feb. 20, Mar. 26, Apr. 16, May 26, June 23, 1913.
NICARAGUA	4	Nov. 30, 1912; Feb. 27, May 1, June 9, 1913.
NORWAY	35	July 20, Aug. 15, Sept. 20, Oct. 17, Nov. 18, 1912; Jan. 3, Feb. 14, Mar. 20, Apr. 15, May 21, June 24, 1913.
ONTARIO	7	July 30, Aug. 31, Dec. 2, 1912; Feb. 1, Mar. 13, May 5, June 20, 1913.
PALESTINE	8	Feb. 28, May 31, 1913.
PARAGUAY	6	July 24, Aug. 27, Nov. 30, 1912; Feb. 27, Apr. 3, June 7, 1913.
PERU	18	July 24, Aug. 24, Sept. 25, Nov. 25, 1912; Jan. 18, Feb. 26, Apr. 3, June 5, 20, 1913.
PORTUGAL	23	July 20, Aug. 15, Sept. 20, Oct. 17, Nov. 18, 1912; Jan. 3, Feb. 14, Mar. 20, Apr. 15, May 21, June 30, 1913.
QUEBEC	7	July 30, Aug. 31, Dec. 2, 1912; Feb. 1, Mar. 13, May 5, June 20, 1913.
QUEENSLAND	20	July 25, Aug. 21, Sept. 24, Oct. 18, Nov. 23, 1912; Jan. 15, Feb. 20, Mar. 26, Apr. 16, May 26, June 23, 1913.
ROUMANIA	9	Aug. 28, Sept. 27, Nov. 25, 1912; Jan. 31, Feb. 27, Apr. 5, June 10, 1913.
RUSSIA	86	July 12, Aug. 8, Sept. 10, Oct. 10, Nov. 21, Dec. 21, 1912; Jan. 9, Feb. 6, Mar. 13, Apr. 10, May 15, June 12, 20, 1913.
SALVADOR	5	Aug. 28, Nov. 30, 1912; Feb. 27, May 1, June 9, 1913.
SERVIA	14	July 30, Aug. 29, Sept. 27, 1912; Jan. 3, Feb. 27, Apr. 5, June 10, 20, 1913.
SIAM	6	Sept. 18, Nov. 8, 1912; Jan. 3, Feb. 28, May 1, June 18, 1913.
SOUTH AUSTRALIA	23	July 25, Aug. 21, Sept. 24, Oct. 17, Nov. 23, 1912; Jan. 15, Feb. 20, Mar. 26, Apr. 16, May 26, June 23, 1913.
SPAIN	35	Aug. 10, Sept. 12, Oct. 26, Nov. 30, Dec. 28, 1912; Feb. 8, Mar. 22, May 3, 31, June 25, 1913.
SWEDEN	65	July 11, Aug. 8, Sept. 12, Oct. 10, Nov. 21, Dec. 12, 1912; Jan. 9, Feb. 6, Mar. 13, Apr. 10, May 15, June 12, 20, 1913.
SWITZERLAND	64	July 6, 27, Aug. 17, 31, Sept. 20, Oct. 12, Nov. 15, Dec. 7, 28, 1912; Jan. 11, Feb. 1, Mar. 8, 29, Apr. 12, May 3, June 7, 28, 1913.
SYRIA	4	Sept. 18, 1912; Jan. 30, Apr. 26, June 10, 1913.
TASMANIA	14	July 20, 1912; Feb. 8, Mar. 8, 29, Apr. 25, May 24, June 27, 1913.
TRINIDAD	5	Sept. 17, Nov. 30, 1912; Feb. 28, May 1, June 28, 1913.
TURKEY	12	July 31, Aug. 31, Sept. 18, Oct. 31, Nov. 8, 1912; Jan. 3, Feb. 26, 28, Apr. 5, June 10, 1913.
UNION OF SOUTH AFRICA	28	July 31, Aug. 29, Sept. 26, Oct. 30, Nov. 25, 1912; Jan. 22, 28, Feb. 27, Apr. 5, May 10, June 20, 1913.

Consignments of exchanges for foreign countries—Continued.

Country.	Number of boxes.	Date of transmission.
URUGUAY...............	19	July 24, Aug. 28, Sept. 26, Oct. 23, Nov. 25, 1912; Jan. 18, Feb. 26, Apr. 3, June 6, 20, 1913.
VENEZUELA.............	16	July 24, Aug. 28, Sept. 26, Nov. 30, 1912; Jan. 29, Feb. 26, Apr. 3, June 7, 1913.
VICTORIA................	31	July 2, Aug. 21, Sept. 24, Oct. 18, Nov. 23, 1912; Jan. 15, Feb. 20, Mar. 26, Apr. 16, May 26, June 23, 1913.
WESTERN AUSTRALIA..	37	July 6, 13, Aug. 17, 24, Sept. 7, 14, 21, Oct. 12, Nov. 5, 16, 30, Dec. 7, 14, 1912; Jan. 4, 18, 25, Feb. 8, 15, Mar. 1, 29, Apr. 11, 25, May 24, June 6, 27, 1913.
WINDWARD AND LEE-WARD ISLANDS.	5	Oct. 31, Nov. 30, 1912; Feb. 28, May 1, June 16, 1913.

A part of the contents of a consignment forwarded under date of May 14 (boxes Nos. 1640–1646 and 7896) was damaged by water while in transit to the Central Statistical Commission in Vienna. Steps will be taken to duplicate as many of the damaged publications as are available for distribution.

FOREIGN DEPOSITORIES OF UNITED STATES GOVERNMENTAL DOCUMENTS.

In accordance with treaty stipulations, and under the authority of the resolutions of Congress of March 2, 1867, and March 2, 1901, setting apart a certain number of documents for exchange with foreign countries, there are now sent regularly to depositories abroad 56 full sets of United States official publications and 36 partial sets. During the year the Province of Bombay and the Corporation of Glasgow were added to the list of recipients of full sets; and Finland, British Guiana, the Free City of Lübeck, and the Province of Madras to the list receiving partial sets. While Finland and the Province of Madras were added to the list of countries receiving partial sets in November, 1912, the Library of Congress has, so far as it was possible to do so, completed the series from 1902 to that time. The recipients of full and partial sets are as follows:

DEPOSITORIES OF FULL SETS.

ARGENTINA: Ministerio de Relaciones Exteriores, Buenos Aires.
AUSTRALIA: Library of the Commonwealth Parliament, Melbourne.
AUSTRIA: K. K. Statistische Zentral-Kommission, Vienna.
BADEN: Universitäts-Bibliothek, Freiburg. (Depository of the Grand Duchy of Baden.)
BAVARIA: Königliche Hof- und Staats-Bibliothek, Munich.
BELGIUM: Bibliothèque Royale, Brussels.
BOMBAY: Secretary to the Government. Bombay.
BRAZIL: Bibliotheca Nacional, Rio de Janeiro.

BUENOS AIRES: Biblioteca de la Universidad Nacional de La Plata.   (Depository of the Province of Buenos Aires.)
CANADA: Library of Parliament, Ottawa.
CHILE: Biblioteca del Congreso Nacional, Santiago.
CHINA: American-Chinese Publication Exchange Department, Shanghai Bureau of Foreign Affairs, Shanghai.
COLOMBIA: Biblioteca Nacional, Bogota.
COSTA RICA: Oficina de Depósito y Canje Internacional de Publicaciones, San José.
CUBA: Secretaria de Estado (Asuntos Generales y Canje Internacional), Habana.
DENMARK: Kongelige Bibliotheket, Copenhagen.
ENGLAND: British Museum, London.
FRANCE: Bibliothèque Nationale, Paris.
GERMANY: Deutsche Reichstags-Bibliothek, Berlin.
GLASGOW: City Librarian, Mitchell Library, Glasgow.
GREECE: Bibliothèque Nationale, Athens.
HAITI: Secrétairerie d'État des Relations Extérieures, Port au Prince.
HUNGARY: Hungarian House of Delegates, Budapest.
INDIA: Department of Education (Books), Government of India, Calcutta.
IRELAND: National Library of Ireland, Dublin.
ITALY: Biblioteca Nazionale Vittorio Emanuele, Rome.
JAPAN: Imperial Library of Japan, Tokyo.
LONDON: London School of Economics and Political Science.   (Depository of the London County Council.)
MANITOBA: Provincial Library, Winnipeg.
MEXICO: Instituto Bibliográfico, Biblioteca Nacional, Mexico.
NETHERLANDS: Library of the States General, The Hague.
NEW SOUTH WALES: Public Library of New South Wales, Sydney.
NEW ZEALAND: General Assembly Library, Wellington.
NORWAY: Storthingets Bibliothek, Christiania.
ONTARIO: Legislative Library, Toronto.
PARIS: Préfecture de la Seine.
PERU: Biblioteca Nacional, Lima.
PORTUGAL: Bibliotheca Nacional, Lisbon.
PRUSSIA: Königliche Bibliothek, Berlin.
QUEBEC: Library of the Legislature of the Province of Quebec, Quebec.
QUEENSLAND: Parliamentary Library, Brisbane.
RUSSIA: Imperial Public Library, St. Petersburg.
SAXONY: Königliche Oeffentliche Bibliothek, Dresden.
SERVIA: Section Administrative du Ministère des Affaires Étrangères, Belgrade.
SOUTH AUSTRALIA: Parliamentary Library, Adelaide.
SPAIN: Servicio del Cambio Internacional de Publicaciones, Cuerpo Facultativo de Archiveros, Bibliotecarios y Arqueólogos, Madrid.
SWEDEN: Kungliga Biblioteket, Stockholm.
SWITZERLAND: Bibliothèque Fédérale, Berne.
TASMANIA: Parliamentary Library, Hobart.
TURKEY: Department of Public Instruction, Constantinople.
UNION OF SOUTH AFRICA: State Library, Pretoria, Transvaal.
URUGUAY: Oficina de Canje Internacional de Publicaciones, Montevideo.
VENEZUELA: Biblioteca Nacional, Carácas.
VICTORIA: Public Library, Melbourne.
WESTERN AUSTRALIA: Public Library of Western Australia, Perth.
WÜRTTEMBERG: Königliche Landesbibliothek, Stuttgart.

ALBERTA : Legislative Library, Edmonton.
ALSACE-LORRAINE : K. Ministerium für Elsass-Lothringen, Strassburg.
BOLIVIA : Ministerio de Colonización y Agricultura, La Paz.
BREMEN : Senatskommission für Reichs- und Auswärtige Angelegenheiten.
BRITISH COLUMBIA : Legislative Library, Victoria.
BRITISH GUIANA : Government Secretary's Office, Georgetown, Demerara.
BULGARIA : Minister of Foreign Affairs, Sofia.
CEYLON : United States Consul, Colombo.
ECUADOR : Biblioteca Nacional, Quito.
EGYPT : Bibliothèque Khédiviale, Cairo.
FINLAND : Chancery of Governor, Helsingfors.
GUATEMALA : Secretary of the Government, Guatemala.
HAMBURG : Senatskommission für die Reichs- und Auswärtigen Angelegenheiten.
HESSE : Grossherzogliche Hof-Bibliothek, Darmstadt.
HONDURAS : Secretary of the Government, Tegucigalpa.
JAMAICA : Colonial Secretary, Kingston.
LIBERIA : Department of State, Monrovia.
LOURENÇO MARQUEZ : Government Library, Lourenço Marquez.
LÜBECK : President of the Senate.
MADRAS, PROVINCE OF : Chief Secretary to the Government of Madras, Public
  Department, Madras.
MALTA : Lieutenant Governor, Valetta.
MONTENEGRO : Ministère des Affaires Étrangères, Cetinje.
NEW BRUNSWICK : Legislative Library, Fredericton.
NEWFOUNDLAND : Colonial Secretary, St. John's.
NICARAGUA : Superintendente de Archivos Nacionales, Managua.
NORTHWEST TERRITORIES : Government Library, Regina.
NOVA SCOTIA : Provincial Secretary of Nova Scotia, Halifax.
PANAMA : Secretaria de Relaciones Exteriores, Panama.
PARAGUAY : Oficina General de Inmigracion, Asuncion.
PRINCE EDWARD ISLAND : Legislative Library, Charlottetown.
ROUMANIA : Academia Romana, Bucharest.
SALVADOR : Ministerio de Relaciones Exteriores, San Salvador.
SIAM : Department of Foreign Affairs, Bangkok.
STRAITS SETTLEMENTS : Colonial Secretary, Singapore.
UNITED PROVINCES OF AGRA AND OUDH : Under Secretary to Government, Alla-
  habad.
VIENNA : Bürgermeister der Haupt- und Residenz-Stadt.

INTERPARLIAMENTARY EXCHANGE OF OFFICIAL JOURNALS.

The interparliamentary exchange of official journals is carried on under a resolution of the Congress approved March 4, 1909, setting aside such number as might be required, not exceeding 100 copies, of the daily issue of the Congressional Record for exchange, through the agency of the Smithsonian Institution, with the legislative chambers of such foreign Governments as might agree to send to the United States current copies of their parliamentary records or like publications. The purpose of this resolution was to enable the institution, on the part of the United States, to more fully carry into

effect the provisions of the convention concluded at Brussels in 1886, providing for the immediate exchange of the official journal.

The Governments of the Province of Buenos Aires, Liberia, and Queensland have entered into this exchange during the year. A complete list of the Governments to which the Congressional Record is now sent is given below:

Argentine Republic.	Italy.
Australia.	Liberia.
Austria.	New South Wales.
Baden.	New Zealand.
Belgium.	Portugal.
Brazil.	Prussia.
Buenos Aires, Province of.	Queensland.
Canada.	Roumania.
Cuba.	Russia.
Denmark.	Servia.
France.	Spain.
Great Britain.	Switzerland.
Greece.	Transvaal.
Guatemala.	Union of South Africa.
Honduras.	Uruguay.
Hungary.	Western Australia.

There are, therefore, at present 32 countries with which the immediate exchange is conducted. To some of these countries, however, two copies of the Congressional Record are sent, one to the upper and one to the lower House of Parliament—the total number transmitted being 37.

RULES GOVERNING THE TRANSMISSION OF EXCHANGES.

The circular containing the rules governing the transmission of exchanges has been revised, and is here reproduced for the information of those who may wish to make use of the facilities of the service in the forwarding of publications.

In effecting the distribution of its first publications abroad, the Smithsonian Institution established relations with certain foreign scientific societies and libraries, by means of which it was enabled to materially assist institutions and individuals of this country in the transmission of their publications abroad, and also foreign societies and individuals in distributing their publications in the United States.

In recent years the Smithsonian Institution has been charged with the duty of conducting the official Exchange Bureau of the United States Government, through which the publications authorized by Congress are exchanged for those of other Governments; and by a formal treaty it acts as intermediary between the learned bodies and scientific and literary societies of the contracting States for the reception and transmission of their publications.

Attention is called to the fact that this is an international and not a domestic exchange service, and that it is designed to facilitate exchanges between the United States and other countries only. As exchanges from domestic sources for addresses in Hawaii, the Philippine Islands, Porto Rico, and other territory

subject to the jurisdiction of the United States do not come within the designation "international," they are not accepted for transmission.

Packages prepared in accordance wih the rules enumerated below will be received by the Smithsonian Institution from persons or institutions of learning in the United States and forwarded to their destinations abroad through its own agents or through the various exchange bureaus in other countries. The Smithsonian agents and many of these bureaus will likewise receive from correspondents in their countries such publications for addresses in the United States and territory subject to its jurisdiction as may be delivered to them under rules similar to those prescribed herein, and will forward them to Washington, after which the Institution will undertake their distribution.

On the receipt of a consignment from a domestic source it is assigned a " record number," which number is placed on each package contained therein. After the packages have been recorded they are packed in boxes with packages from other senders intended for the same countries, and are forwarded by fast freight to the bureaus or agencies abroad which have undertaken to distribute exchanges in those countries. To Great Britain and Germany shipments are made weekly; to all other countries at intervals not exceeding one month.

Consignments from abroad for correspondents in the United States and its outlying possessions are distributed by mail under frank.

The Institution assumes no responsibility in the transmission of packages intrusted to its care, but at all times uses its best endeavors to forward exchanges to their destinations as promptly as possible.

RULES.

The rules governing the Smithsonian International Exchange Service are as follows:

1. Consignments from correspondents in the United States containing packages for transmission abroad should be addressed " Smithsonian Institution, International Exchanges, Washington, D. C."

2. In forwarding a consignment the sender should mail a letter to the Institution, stating by what route it is being shipped, and the number of boxes or parcels which it comprises. A list giving the name and address of each consignee should also be furnished.

3. Packages should be legibly addressed, using, when practicable, the language of the country to which they are to be forwarded. In order to avoid any possible dispute as to ownership, names of individuals should be omitted from packages intended for societies and other establishments.

4. Packages should be securely wrapped in stout paper and, when necessary, tied with strong twine. Cardboard should be used in some instances to protect plates from crumpling.

5. Letters are not permitted in exchange packages

6. If donors desire acknowledgments, packages may contain receipt forms to be signed and returned by the establishment or individual addressed. Should publications be desired in exchange, a request to that effect may be printed on the receipt form or on the package.

7. Exchanges intended for transmission abroad must be delivered to the Smithsonian Institution *with all charges to Washington prepaid.*

8. The work carried on by the International Exchange Service is not in any sense of a commercial nature, but is restricted to the transmission of publications sent as exchanges or donations. Books ordered through the trade are therefore necessarily excluded.

9. Specimens are not accepted for distribution, except when permission has been obtained from the Institution.

LIST OF BUREAUS OR AGENCIES THROUGH WHICH EXCHANGES ARE TRANSMITTED.

The following is a list of the bureaus or agencies through which exchanges are transmitted:

ALGERIA, *via* France.

ANGOLA, *via* Portugal.

ARGENTINA: Comisión Protectora de Bibliotecas Populares, Reconquista 538, Buenos Aires.

AUSTRIA: K. K. Statistische Zentral-Kommission, Vienna.

AZORES, *via* Portugal.

BELGIUM: Service Belge des Échanges Internationaux, Rue du Musée 5, Brussels.

BOLIVIA: Oficina Nacional de Estadística, La Paz.

BRAZIL: Serviço de Permutações Internacionaes, Bibliotheca Nacional, Rio de Janeiro.

BRITISH COLONIES: Crown Agents for the Colonies, London.[1]

BRITISH GUIANA: Royal Agricultural and Commercial Society, Georgetown.

BRITISH HONDURAS: Colonial Secretary, Belize.

BULGARIA: Institutions Scientifiques de S. M. le Roi de Bulgarie, Sofia.

CANARY ISLANDS, *via* Spain.

CHILE: Servicio de Canjes Internacionales, Biblioteca Nacional, Santiago.

CHINA: Zi-ka-wei Observatory, Shanghai.

COLOMBIA: Oficina de Canjes Internacionales y Reparto, Biblioteca Nacional, Bogota.

COSTA RICA: Oficina de Depósito y Canje Internacional de Publicaciones, San José.

DENMARK: Kongelige Danske Videnskabernes, Selskab, Copenhagen.

DUTCH GUIANA: Surinaamsche Koloniale Bibliotheek, Paramaribo.

ECUADOR: Ministerio de Relaciones Exteriores, Quito.

EGYPT: Government Publications Office, Printing Department, Cairo.

FRANCE: Service Français des Échanges Internationaux, 110 Rue de Grenelle, Paris.

GERMANY: Amerika-Institut, Berlin, N. W. 7.

GREAT BRITAIN AND IRELAND: Messrs. William Wesley & Son, 28 Essex Street, Strand, London.

GREECE: Bibliothèque Nationale, Athens.

GREENLAND, *via* Denmark.

GUADELOUPE, *via* France.

GUATEMALA: Instituto Nacional de Varones, Guatemala.

GUINEA, *via* Portugal.

HAITI: Secrétaire d'État des Relations Extérieures, Port au Prince.

HONDURAS: Biblioteca Nacional, Tegucigalpa.

HUNGARY: Dr. Julius Pikler, Municipal Office of Statistics, Váci-utca 80, Budapest.

ICELAND, *via* Denmark.

INDIA: India Store Department, India Office, London.

ITALY: Ufficio degli Scambi Internazionali, Biblioteca Nazionale Vittorio Emanuele, Rome.

JAMAICA: Institute of Jamaica, Kingston.

JAPAN: Imperial Library of Japan, Tokyo.

JAVA, *via* Netherlands.

KOREA: His Imperial Japanese Majesty's Residency-General, Seoul.

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[1] This method is employed for communicating with several of the British colonies with which no medium is available for forwarding exchanges direct.

LIBERIA : Bureau of Exchanges, Department of State, Monrovia.
LOURENÇO MARQUEZ: Government Library, Lourenço Marquez.
LUXEMBURG, *via* Germany.
MADAGASCAR, *via* France.
MADEIRA, *via* Portugal.
MONTENEGRO: Ministère des Affaires Étrangères, Cetinje.
MOZAMBIQUE, *via* Portugal.
NETHERLANDS: Bureau Scientifique Central Néerlandais, Bibliothèque de l'Université, Leyden.
NEW GUINEA, *via* Netherlands.
NEW SOUTH WALES: Public Library of New South Wales, Sydney.
NEW ZEALAND: Dominion Museum, Wellington.
NICARAGUA: Ministerio de Relaciones Exteriores, Managua.
NORWAY: Kongelige Norske Frederiks Universitet Bibliotheket, Christiania.
PANAMA: Secretaria de Relaciones Exteriores, Panama.
PARAGUAY: Ministerio de Relaciones Exteriores, Asuncion.
PERSIA : Board of Foreign Missions of the Presbyterian Church, New York City.
PERU: Oficina de Reparto, Depósito y Canje Internacional de Publicaciones, Ministerio de Fomento, Lima.
PORTUGAL: Serviço de Permutações Internacionaes, Bibliotheca Nacional, Lisbon.
QUEENSLAND: Bureau of Exchanges of International Publications, Chief Secretary's Office, Brisbane.
ROUMANIA: Academia Romana, Bucharest.
RUSSIA: Commission Russe des Échanges Internationaux, Bibliothèque Impériale Publique, St. Petersburg.
SALVADOR: Ministerio de Relaciones Exteriores, San Salvador.
SERVIA : Section Administrative du Ministère des Affaires Étraugères, Belgrade.
SIAM : Department of Foreign Affairs, Bangkok.
SOUTH AUSTRALIA : Public Library of South Australia, Adelaide.
SPAIN: Servicio del Cambio Internacional de Publicaciones, Cuerpo Facultativo de Archiveros, Bibliotecarios y Arqueólogos, Madrid.
SUMATRA, *via* Netherlands.
SWEDEN: Kongliga Svenska Vetenskaps Akademien, Stockholm.
SWITZERLAND: Service des Échanges Internationaux, Bibliothèque Fédérale Centrale, Berne.
SYRIA: Board of Foreign Missions of the Presbyterian Church, New York.
TASMANIA : Secretary to the Premier, Hobart.
TRINIDAD : Royal Victoria Institute of Trinidad and Tobago, Port-of-Spain.
TUNIS, *via* France.
TURKEY: American Board of Commissioners for Foreign Missions, Boston.
UNION OF SOUTH AFRICA: Government Printing Works, Pretoria, Transvaal.
URUGUAY: Oficina de Canje Internacional, Montevideo.
VENEZUELA : Biblioteca Nacional, Caracas.
VICTORIA : Public Library of Victoria. Melbourne.
WESTERN AUSTRALIA: Public Library of Western Australia, Perth.
WINDWARD AND LEEWARD ISLANDS: Imperial Department of Agriculture, Bridgetown, Barbados.

Respectfully submitted.

F. W. TRUE,
Assistant Secretary in Charge
of Library and Exchanges.

Dr. CHARLES D. WALCOTT,
Secretary of the Smithsonian Institution.
SEPTEMBER 27, 1913.

APPENDIX 4.

REPORT ON THE NATIONAL ZOOLOGICAL PARK.

SIR: I have the honor to submit herewith a report of the operations of the National Zoological Park for the fiscal year ending June 30, 1913.

The general appropriation made by Congress for the improvement and maintenance during that year was $100,000. The cost of food for the animals was $20,235, which is somewhat less than during the previous year, being due to the decline in prices of forage from the extremely high rates which then prevailed. The expenditures for upkeep were greater than usual, especially as to out-door cages, inclosures, and fences.

ACCESSIONS.

During the previous year, owing to the necessity of providing a fireproof building for the central heating plant and making certain urgently needed small improvements, only a small sum was used for the purchase of animals. During the present year several important animals have been added, including a pair of young African elephants, three dromedaries, a pair of cheetahs, several species of gazelles, and other animals, purchased from the Government Zoological Garden at Giza, Egypt. These were engaged some time before the end of the fiscal year, but, as explained·below, they did not finally reach the park until a little after the end of the period covered by this report.

Seven ostriches from southern California were purchased, and two moose, a male and a female, were obtained by exchange from the Rocky Mountains National Park in Alberta, Canada. The accessions, with the animals from Giza, included 15 species not previously represented in the collection.

The total amount expended for purchase and transportation of animals was $6,900.

Mammals and birds born and hatched in the park numbered 78 and included polar, grizzly, and Alaskan brown bears, alpaca, llama, American tapir, chamois, harnessed antelope, deer of several species, with some other mammals and various birds.

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EXCHANGES.

The number of exchanges was smaller than usual. As already mentioned, two moose were received from the Rocky Mountains National Park and several animals from dealers.

ANIMALS FROM GIZA.

In the latter part of March, 1913, an offer of some desirable animals was received from the Government Zoological Garden at Giza, Egypt. This offer included two young African elephants, a male and a female, and a number of other less important animals. The two elephants were engaged for the park, together with three dromedaries and two Arabian baboons. As the Egyptian authorities required the animals to be accepted at their gardens, it was thought advisable to send the head keeper of the park to receive them and accompany them during transportation. He left Washington May 15, 1912, and arrived at Giza on June 19. On his arrival he found that several other desirable animals were available there and was authorized by cable to secure them for the park, so that there were altogether 21 animals in the shipment. It was necessary to go to London to arrange for transportation, and on the way from there to Egypt the zoological gardens at Amsterdam, Rotterdam, Antwerp, Cologne, and Rome were visited.

ANIMALS IN THE COLLECTION JUNE 30, 1913.

MAMMALS.

Grivet monkey (*Cercopithecus sabæus*)_	1
Green monkey (*Cercopithecus callitrichus*) _____	1
Mona monkey (*Cercopithecus mona*)__	2
Diana monkey (*Cercopithecus diana*)__	1
Sooty mangabey (*Cercocebus fuliginosus*) _____	2
Bonnet monkey (*Macacus sinicus*)____	1
Macaque monkey (*Macacus cynomolgus*) _____	3
Pig-tailed monkey (*Macacus nemestrinus*) _____	4
Rhesus monkey (*Macacus rhesus*)____	16
Brown macaque (*Macacus arctoides*)__	3
Japanese monkey (*Macacus fuscatus*)__	3
Moor monkey (*Macacus maurus*)____	1
Black ape (*Cynopithecus niger*)_____	1
Chacma (*Papio porcarius*)_____	1
Hamadryas baboon (*Papio hamadryas*)_	1
Mandrill (*Papio maimon*)_____	3
Gray spider monkey (*Ateles geoffroyi*)__	1
White-throated capuchin (*Cebus hypoleucus*)_____	1
Brown monkey (*Cebus fatuellus*)_____	1
Durukuli (*Nyctipithecus trivirgatus*)__	2
Ruffed lemur (*Lemur varius*)_____	2
Ring-tailed lemur (*Lemur catta*)_____	3

Polar bear (*Thalarctos maritimus*)____	2
European brown bear (*Ursus arctos*)__	2
Kadiak bear (*Ursus middendorffi*)_____	1
Yakutat bear (*Ursus dalli*)_____	1
Alaskan brown bear (*Ursus gyas*)____	3
Hybrid bear (*Ursus gyas-arctos*)_____	1
Kidder's bear (*Ursus kidderi*)_____	2
Himalayan bear (*Ursus thibetanus*)__	1
Grizzly bear (*Ursus horribilis*)_____	3
Black bear (*Ursus americanus*)_____	9
Cinnamon bear (*Ursus americanus*)___	2
Malay bear (*Ursus malayanus*)_____	2
Sloth bear (*Melursus ursinus*)_____	1
Kinkajou (*Cercoleptes caudivolvulus*)_	1
Cacomistle (*Bassariscus astuta*)_____	1
Gray coatimundi (*Nasua narica*)_____	5
Raccoon (*Procyon lotor*)_____	19
American badger (*Taxidea taxus*)____	2
Common skunk (*Mephitis putida*)_____	4
American marten (*Mustela americana*)_	2
Fisher (*Mustela pennantii*)_____	1
Mink (*Putorius vison*)_____	5
Common ferret (*Putorius putorius*)___	1
Black-footed ferret (*Putorius nigripes*)_	2
North American otter (*Lutra canadenis*)_____	5
Eskimo dog (*Canis familiaris*)_____	2

Animals in the collection June 30, 1913—Continued.

MAMMALS—Continued.

Dingo (*Canis dingo*)	2
Gray wolf (*Canis occidentalis*)	4
Black wolf (*Canis occidentalis*)	1
Coyote (*Canis latrans*)	3
Woodhouse's coyote (*Canis frustror*)	3
Red fox (*Vulpes pennsylvanicus*)	4
Swift fox (*Vulpes velox*)	2
Arctic fox (*Vulpes lagopus*)	2
Gray fox (*Urocyon cinereo-argenteus*)	5
Spotted hyena (*Hyæna crocuta*)	1
African palm civet (*Viverra civetta*)	1
Common genet (*Genetta genetta*)	2
Sudan lion (*Felis leo*)	2
Kilimanjaro lion (*Felis leo sabakicnsis*)	4
Tiger (*Felis tigris*)	1
Cougar (*Felis oregonensis hippolestes*)	3
Jaguar (*Felis onca*)	1
Leopard (*Felis pardus*)	2
Black leopard (*Felis pardus*)	1
Serval (*Felis serval*)	1
Ocelot (*Felis pardalis*)	1
Canada lynx (*Lynx canadensis*)	1
Bay lynx (*Lynx rufus*)	6
Spotted lynx (*Lynx rufus texensis*)	2
Florida lynx (*Lynx rufus floridanus*)	1
Steller's sea lion (*Eumetopias stelleri*)	1
California sea lion (*Zalophus californianus*)	2
Northern fur seal (*Callotaria alascana*)	1
Harbor seal (*Phoca vitulina*)	2
Fox squirrel (*Sciurus niger*)	9
Western fox squirrel (*Sciurus ludovicianus*)	8
Gray squirrel (*Sciurus carolinensis*)	40
Black squirrel (*Sciurus carolinensis*)	20
Albino squirrel (*Sciurus carolinensis*)	1
Panama squirrel	1
Prairie dog (*Cyomys ludovicianus*)	28
Woodchuck (*Arctomys monax*)	3
Albino woodchuck (*Arctomys monax*)	1
Black woodchuck (*Arctomys monax*)	1
Alpine marmot (*Arctomys marmotta*)	2
American beaver (*Castor canadensis*)	2
Coypu (*Myocastor coypus*)	1
Hutia-conga (*Capromys pilorides*)	2
Indian porcupine (*Hystrix leucura*)	2
Canada porcupine (*Erethizon dorsatus*)	1
Canada porcupine (*Erethizon dorsatus*) albino	1
Western porcupine (*Erethizon epixanthus*)	1
Mexican agouti (*Dasyprocta mexicana*)	1
Azara's agouti (*Dasyprocta azaræ*)	2
Crested agouti (*Dasyprocta cristata*)	2
Hairy-rumped agouti (*Dasyprocta prymnolopha*)	4
Paca (*Cælogenys paca*)	2
Guinea pig (*Cavia cutleri*)	13
Patagonian cavy (*Dolichotis patagonica*)	3
Capybara (*Hydrochœrus capybara*)	1
Domestic rabbit (*Lepus cuniculus*)	37
Cape hyrax (*Procavia capensis*)	1

Indian elephant (*Elephas maximus*)	1
Brazilian tapir (*Tapirus americanus*)	5
Grevy's zebra (*Equus grevyi*)	1
Zebra-donkey hybrid (*Equus grevyi-asinus*)	1
Grant's zebra (*Equus burchelli granti*)	1
Collared peccary (*Dicotyles angulatus*)	3
Wild boar (*Sus scrofa*)	2
Northern wart hog (*Phacochœrus africanus*)	2
Hippopotamus (*Hippopotamus amphibius*)	1
Guanaco (*Lama huanachus*)	3
Llama (*Lama glama*)	10
Alpaca (*Lama pacos*)	3
Vicugna (*Lama vicugna*)	2
Bactrian camel (*Camelus bactrianus*)	2
Muntjac (*Cervulus muntjac*)	1
Sambar deer (*Cervus aristotelis*)	2
Philippine deer (*Cervus philippinus*)	1
Hog deer (*Cervus porcinus*)	6
Barasingha deer (*Cervus duvaucelii*)	13
Axis deer (*Cervus axis*)	8
Japanese deer (*Cervus sika*)	16
Red deer (*Cervus elaphus*)	7
American elk (*Cervus canadensis*)	6
Fallow deer (*Cervus dama*)	7
Moose (*Alces americanus*)	1
Virginia deer (*Odocoileus virginianus*)	12
Mule deer (*Odocoileus hemionus*)	1
Columbian black-tailed deer (*Odocoileus columbianus*)	1
Cuban deer (*Odocoileus sp.*)	1
Coke's hartebeest (*Bubalis cokei*)	1
Blessbok (*Damaliscus albifrons*)	1
White-tailed gnu (*Connochætes gnu*)	1
Defassa water buck (*Cobus defassa*)	1
Indian antelope (*Antilope cervicapra*)	3
Nilgai (*Boselaphus tragocamelus*)	2
Congo harnessed antelope (*Tragelaphus gratus*)	2
Chamois (*Rupicapra tragus*)	3
Tahr (*Hemitragus jemlaicus*)	6
Common goat (*Capra hircus*)	8
Angora goat (*Capra hircus*)	5
Barbary sheep (*Ovis tragelaphus*)	15
Barbados sheep (*Ovis aries-tragelaphus*)	13
Anoa (*Anoa depressicornis*)	1
East African buffalo (*Buffelus neumanni*)	1
Zebu (*Bibos indicus*)	3
Yak (*Poëphagus grunniens*)	5
American bison (*Bison americanus*)	15
Hairy armadillo (*Dasypus villosus*)	3
Wallaroo (*Macropus robustus*)	3
Red kangaroo (*Macropus rufus*)	3
Bennett's wallaby (*Macropus ruficollis bennetti*)	1
Virginia opossum (*Didelphys marsupialis*)	2
Virginia opossum (*Didelphys marsupialis*) albino	1
Common wombat (*Phascolomys mitchelli*)	1

Animals in the collection June 30, 1913—Continued.

BIRDS.

European blackbird (*Merula merula*)_ 1
Mocking bird (*Mimus polyglottos*)___ 1
Catbird (*Dumetella carolinensis*)_____ 1
Brown thrasher (*Toxostoma rufus*)___ 1
Japanese robin (*Liothrix luteus*)_____ 10
White-cheeked bulbul (*Pycnonotus leucogenys*)_____ 1
Black bulbul (*Pycnonotus pygœus*)____ 1
Laughing thrush (*Garrulax leucolophus*)_____ 2
Bishop finch (*Tanagra episcopus*)_____ 4
Orange-cheeked waxbill (*Estrelda melpoda*)_____ 7
Cordon-bleu (*Estrelda phœnicotis*)____ 8
Magpie finch (*Spermestes fringilloides*)_ 2
Cut-throat finch (*Amadina fasciata*)__ 10
Zebra finch (*Amadina castanotis*)_____ 4
Black-headed finch (*Munia atricapilla*)_ 7
Three-colored finch (*Munia malacca*)__ 6
White-headed finch (*Munia maja*)____ 9
Nutmeg finch (*Munia punctularia*)___ 6
Java sparrow (*Munia oryzivora*)_____ 13
White Java sparrow (*Munia oryzivora*)_____ 12
Sharp-tailed grass finch (*Poëphila acuticauda*)_____ 2
Silver-bill finch (*Aidemosyne cantans*)_ 12
Chestnut-breasted finch (*Donacola castaneothorax*)_____ 6
Bearded finch (*Spermophila sp.*)_____ 2
Napoleon weaver (*Pyromelana afra*)__ 4
Madagascar weaver (*Foudia madagascariensis*)_____ 4
Red-billed weaver (*Quelea quelea*)____ 8
Whydah weaver (*Vidua paradisea*)____ 28
Painted bunting (*Passerina ciris*)_____ 1
Red-crested cardinal (*Paroaria cucullata*)_____ 8
Rose-breasted grosbeak (*Zamelodia ludoviciana*)_____ 1
Common cardinal (*Cardinalis cardinalis*)_____ 1
Siskin (*Spinus spinus*)_____ 5
Saffron finch (*Sycalis flaveola*)_____ 19
European goldfinch (*Carduelis elegans*)_ 2
Yellow-hammer (*Emberiza citrinella*)_ 1
Common canary (*Serinus canarius*)___ 26
Linnet (*Linota cannabina*)_____ 4
Bullfinch (*Pyrrhula europœa*)_____ 1
Cowbird (*Molothrus ater*)_____ 1
Glossy starling (*Lamprotornis caudatus*)_____ 1
Malabar mynah (*Poliopsar malabaricus*)_____ 2
European raven (*Corvus corax*)_____ 1
American raven (*Corvus corax sinuatus*)_____ 2
Common crow (*Corvus brachyrhynchos*)_____ 1
Green jay (*Xanthoura luxuosa*)_____ 1
White-throated jay (*Garrulus leucotis*)_ 2
Blue jay (*Cyanocitta cristata*)_____ 3
American magpie (*Pica pica hudsonica*)_____ 2
Red-billed magpie (*Urocissa occipitalis*)_ 2
Piping crow (*Gymnorhina tibicen*)____ 2

Yellow tyrant (*Pitangus derbianus*)__ 2
Giant kingfisher (*Dacelo gigas*)_____ 1
Yellow-breasted toucan (*Rhamphastos carinatus*)_____ 3
Sulphur-crested cockatoo (*Cacatua galerita*)_____ 3
White cockatoo (*Cacatua alba*)_____ 6
Leadbeater's cockatoo (*Cacatua leadbeateri*)_____ 1
Bare-eyed cockatoo (*Cacatua gymnopis*) 4
Roseate cockatoo (*Cacatua roseicapilla*)_____ 12
Gang-gang cockatoo (*Callocephalon galeatum*)_____ 1
Yellow and blue macaw (*Ara araraunea*)_____ 2
Red and yellow and blue macaw (*Ara macao*)_____ 9
Red and blue macaw (*Ara chloroptera*)_____ 2
Great green macaw (*Ara militaris*)___ 1
Mexican conure (*Conurus holochlorus*)_ 1
Carolina paroquet (*Conuropsis carolinensis*)_____ 1
Cuban parrot (*Amazona leucocephala*)_ 2
Orange-winged amazon (*Amazona amazonica*)_____ 2
Porto Rican amazon (*Amazona vittata*)_____ 1
Yellow-shouldered amazon (*Amazona ochroptera*)_____ 2
Yellow-fronted amazon (*Amazona ochrocephala*)_____ 2
Red-fronted amazon (*Amazona rhodocorytha*)_____ 1
Yellow-headed amazon (*Amazona levaillanti*)_____ 2
Blue-fronted amazon (*Amazona œstiva*)_____ 2
Lesser vasa parrot (*Coracopsis nigra*)_ 2
Banded parrakeet (*Palæornis fasciata*)_ 1
Alexandrine parrakeet (*Palæornis alexandri*)_____ 4
Rosella parrakeet (*Platycercus eximius*)_____ 2
Love bird (*Agapornis pullaria*)_____ 2
Green parrakeet (*Loriculus sp.*)_____ 2
Shell parrakeet (*Melopsittacus undulatus*)_____ 9
Great horned owl (*Bubo virginianus*)_ 8
Arctic horned owl (*Bubo virginianus subarcticus*)_____ 1
Screech owl (*Otus asio*)_____ 4
Barred owl (*Strix varia*)_____ 3
Barn owl (*Aluco pratincola*)_____ 8
Sparrow hawk (*Falco sparverius*)____ 1
Bald eagle (*Haliæetus leucocephalus*)_ 12
Alaskan bald eagle (*Haliæetus leucocephalus alascanus*)_____ 1
Golden eagle (*Aquila chrysaëtos*)_____ 2
Harpy eagle (*Thrasaëtus harpyia*)____ 1
Chilian eagle (*Geranoaëtus melanoleucus*)_____ 1
Crowned hawk eagle (*Spizaëtus coronatus*)_____ 1
Red-shouldered hawk (*Buteo lineatus*)_ 1

Animals in the collection June 30, 1913—Continued.

BIRDS—Continued.

Venezuelan hawk	1
Caracara (*Polyborus cheriway*)	3
Lammergeyer (*Gypaëtus barbatus*)	2
South American condor (*Sarcorhamphus gryphus*)	2
California condor (*Gymnogyps californianus*)	3
Griffon vulture (*Gyps fulvus*)	2
Cinereous vulture (*Vultur monachus*)	2
Egyptian vulture (*Neophron percnopterus*)	1
Turkey vulture (*Cathartes aura*)	4
Black vulture (*Catharista urubi*)	2
King vulture (*Gypagus papa*)	2
Red-billed pigeon (*Columba flavirostris*)	4
Mourning dove (*Zenaidura macroura*)	8
Peaceful dove (*Geopelia tranquilla*)	2
Collared turtle dove (*Turtur risorius*)	13
Cape masked dove (*Œna capensis*)	5
Victoria crowned pigeon (*Goura victoria*)	1
Purplish guan (*Penelope purpurascens*)	1
Crested curassow (*Crax alector*)	1
Mexican curassow (*Crax globicera*)	2
Daubenton's curassow (*Crax daubentoni*)	1
Wild turkey (*Meleagris gallopavo silvestris*)	5
Peafowl (*Pavo cristata*)	60
Jungle fowl (*Gallus bankiva*)	1
English pheasant (*Phasianus colchicus*)	1
Reeves's pheasant (*Phasianus reevesi*)	1
Golden pheasant (*Thaumalea picta*)	1
Silver pheasant (*Euplocamus nycthemerus*)	1
European quail (*Coturnix communis*)	1
Hungarian partridge (*Perdix perdix*)	1
Bobwhite (*Colinus virginianus*)	3
Mountain quail (*Oreortyx picta*)	2
Scaled quail (*Callipepla squamata*)	2
California quail (*Lophortyx californica*)	1
Gambel's quail (*Lophortyx gambeli*)	3
Massena quail (*Cyrtonyx montezumœ*)	7
Purple gallinule (*Porphyrio cœrulea*)	1
Black-backed gallinule (*Porphyrio melanotus*)	2
Martinique gallinule (*Ionornis martinicus*)	1
Florida gallinule (*Gallinula galeata*)	1
American coot (*Fulica americana*)	11
Flightless rail (*Ocydromus australis*)	1
Common cariama (*Cariama cristata*)	1
Demoiselle crane (*Anthropoides virgo*)	7
Crowned crane (*Balearica pavonina*)	2
Sandhill crane (*Grus mexicana*)	2
Australian crane (*Grus australasiana*)	1
European crane (*Grus cinerea*)	2
Sarus crane (*Grus antigone*)	1
Indian white crane (*Grus leucogeranus*)	2
Ruff (*Machetes pugnax*)	2

Black-crowned night heron (*Nycticorax nycticorax nævius*)	8
Little blue heron (*Florida cœrulea*)	1
Reddish egret (*Dichromanassa rufescens*)	1
Snowy egret (*Egretta candidissima*)	4
Great white heron (*Herodias egretta*)	1
Great blue heron (*Ardea herodias*)	3
Great black-crowned heron (*Ardea cocoi*)	1
Boat-bill (*Cancroma cochlearia*)	2
Black stork (*Ciconia nigra*)	1
Marabou stork (*Leptoptilus dubius*)	1
Wood ibis (*Mycteria americana*)	2
Sacred ibis (*Ibis œthiopica*)	4
White ibis (*Guara alba*)	21
Roseate spoonbill (*Ajaja ajaja*)	1
European flamingo (*Phœnicopterus antiquorum*)	3
Crested screamer (*Chauna cristata*)	2
Whistling swan (*Olor columbianus*)	5
Mute swan (*Cygnus gibbus*)	4
Black swan (*Chenopis atrata*)	1
Muscovy duck (*Cairina moschata*)	1
White muscovy duck (*Cairina moschata*)	2
Wandering tree-duck (*Dendrocygna arcuata*)	7
Fulvous tree-duck (*Dendrocygna bicolor*)	2
Brant (*Branta bernicla glaucogastra*)	1
Canada goose (*Branta canadensis*)	7
Hutchins's goose (*Branta canadensis hutchinsii*)	3
Lesser snow goose (*Chen hyperboreus*)	2
Greater snow goose (*Chen hyperboreus nivalis*)	1
American white-fronted goose (*Anser albifrons gambeli*)	3
Chinese goose (*Anser cygnoides*)	3
Scaup duck (*Marila marila*)	5
Canvasback (*Marila valisneria*)	1
Red-headed duck (*Marila americana*)	2
Wood duck (*Aix sponsa*)	8
Mandarin duck (*Dendronessa galericulata*)	5
Pintail (*Dafila acuta*)	4
Shoveler duck (*Spatula clypeata*)	1
Black duck (*Anas rubripes*)	1
Mallard (*Anas platyrhynchos*)	13
American white pelican (*Pelecanus erythrorhynchos*)	10
European white pelican (*Pelecanus onocrotalus*)	1
Roseate pelican (*Pelecanus roseus*)	1
Brown pelican (*Pelecanus occidentalis*)	5
Florida cormorant (*Phalacrocorax auritis floridanus*)	14
Mexican cormorant (*Phalacrocorax vigua mexicanus*)	1
Water turkey (*Anhinga anhinga*)	5
Roseate tern (*Sterna dougalli*)	3
Royal tern (*Sterna maxima*)	4
Black-backed gull (*Larus marinus*)	1

*Animals in the collection June 30, 1913—*Continued.

BIRDS—Continued.

Herring gull (*Larus argentatus*) _____	4
American herring gull (*Larus argentatus smithsonianus*) _____	5
Laughing gull (*Larus atricilla*) _____	2
South African ostrich (*Struthio australis*) _____	7
Somali ostrich (*Struthio molybdophanes*) _____	1
Common cassowary (*Casuarius galeatus*) _____	1
Common rhea (*Rhea americana*) _____	3
Emu (*Dromæus novæ hollandiæ*) _____	1

REPTILES.

Alligator (*Alligator mississippiensis*) __	17
Sharp-nosed crocodile (*Crocodilus americanus*) _____	1
Painted turtle (*Chrysemys picta*) _____	4
Diamond-back terrapin (*Malacoclemys palustris*) _____	1
Three-toed box-tortoise (*Cistudo triunguis*) _____	6
Painted box-tortoise (*Cistudo ornata*) _	5
Gopher turtle (*Xerobates polyphemus*) _	1
Duncan Island tortoise (*Testudo ephippium*) _____	2
Albemarle Island tortoise (*Testudo vicina*) _____	1
Horned lizard (*Phrynosoma cornutum*) _	3
Gila monster (*Heloderma suspectum*) _	5
Glass snake (*Ophisaurus ventralis*) ___	1
Regal python (*Python reticulatus*) ____	1
Anaconda (*Eunectes murinus*) _____	2
Velvet snake (*Epicrates cenchis*) ____	1
Cuban tree-boa (*Epicrates angulifer*) __	1
Spreading adder (*Heterodon platyrhinus*) _____	1
Black snake (*Zamenis constrictor*) ____	3
Coach-whip snake (*Zamenis flagellum*) _	1
Corn snake (*Coluber guttatus*) _____	1
Common chicken snake (*Coluber quadrivittatus*) _____	1
Gopher snake (*Compsosoma corais couperii*) _____	1
Pine snake (*Pityophis melanoleucus*) __	4
Bull snake (*Pityophis sayi*) _____	1
King snake (*Ophibolus getulus*) _____	1
Common garter snake (*Eutænia sirtalis*) _____	1
Texas water snake (*Eutænia proxima*) _	1
Water moccasin (*Ancistrodon piscivorus*) _____	1
Copperhead (*Ancistrodon contortrix*) __	2
Diamond rattlesnake (*Crotalus adamanteus*) _____	3
Banded rattlesnake (*Crotalus horridus*) _____	1

GIFTS.

Mr. Raymond Adams, Washington, D. C., an alligator.

Dr. J. S. Billupp, Leeland, Md., an American magpie.

Mr. M. E. Boyd, Washington, D. C., a horned lizard.

Mr. August Busck, Washington, D. C., two marmosettes.

Mr. W. M. Chrissinger, Hagerstown, Md., a black snake.

Mrs. Eugenia S. Cleary, Washington, D. C., a common canary.

Mr. Wallace Evans, Oak Park, Ill., four mink.

Capt. W. E. P. French, Washington, D. C., an alligator.

Mr. F. P. Hall, Washington, D. C., three alligators.

Mr. Kidwell, Washington, D. C., a bald eagle.

Mr. M. S. Lawrence, Washington, D. C., a common opossum.

Mr. De Witt T. Leach, Washington, D. C., a woodchuck.

Mr. Ralph W. Lee, Washington, D. C., an alligator.

Miss Clare and Mr. James McCall, Mapleton, Pa., a banded rattlesnake.

Mr. D. McLanahan, Washington, D. C., a barred owl.

Mr. E. B. McLean, Washington, D. C., a skunk, two raccoons, and a toucan.

Mr. J. W. Mills, Washington, D. C., an alligator.

Mr. Victor Mindeleff, Washington, D. C., a crocodile.

Mr. Thomas Moreland, Washington, D. C., a barn owl.

Hon. L. P. Padgett, Columbia, Tenn., a gray coatimundi.

Capt. A. W. Perry, Washington, D. C., a western mocking bird.

Capt. R. B. Putnam, Washington, D. C., a gray coatimundi.

Mr. F. J. Raymond, Washington, D. C., a green parrot.

Dr. C. W. Richmond, Washington, D. C., two barn owls.

Mrs. Ricketson, Washington, D. C., a common raccoon.
Mr. Richard A. Sargent, Washington, D. C., a common canary.
Mrs. Gurnon P. Scott, Washington, D. C., a shell parrakeet.
Mr. E. T. Seton, Cos Cob, Conn., three common skunks.
Mr. Ellis Spear, Washington, D. C., two common canaries.
Miss Straub, Washington, D. C., a green parrot.
Mr. H. E. Thomas, Washington, D. C., a black snake.
Mrs. E. St. Clair Thompson, Washington, D. C., a common canary.
Mrs. C. V. Williams, Washington, D. C., an alligator.
Hon. Woodrow Wilson, Washington, D. C., a horned lizard.
The Zoological Society of Philadelphia, six muskrats.
Unknown donors, a screech owl, five barn owls, an English pheasant, and an alligator.

LOSSES OF ANIMALS.

The most serious loss was among the ruminants. An eland, a bontebok, a Coke's hartebeest, and a harnessed antelope died from tuberculosis; a moose and a reindeer from enteritis; two tahr goats from pneumonia; and an American bison, 21 years old, from arteriosclerosis. A fur seal also died from enteritis and a grizzly bear that when captured, 19 years before, weighed 730 pounds was killed because of its general decrepitude. A number of birds were lost through the depredations of raccoons and other animals living at large in the park. The night herons had increased to such an extent in the flying cage that they interfered with the nesting of other birds there, and the greater part of them (114) were disposed of, a few as gifts to other zoological collections.

Of animals that died in the park, 107 were transferred to the National Museum. Autopsies were made as heretofore by the Pathological Division of the Bureau of Animal Industry, Department of Agriculture.[1]

STATEMENT OF THE COLLECTION.

ACCESSIONS DURING THE YEAR.

Presented	66
Purchased	162
Born and hatched in National Zoological Park	78
Received in exchange	18
Deposited in National Zoological Park	6
Captured in National Zoological Park	1
Total	331

[1] The causes of death were reported to be as follows: Enteritis, 37; gastritis, 1; impaction of bowel, 3; pneumonia, 14; tuberculosis, 10; congestion of lungs, 4; aspergillosis, 4; malignant catarrh of nose and throat, 1; inflammation of pharynx and larynx, 1; congestion of liver, 1; septicemia, 3; sarcoma, 1; abscess, 1; gangrene of thyroid gland, 1; generalized fat necrosis, 1: arteriosclerosis, 1; umbilical infection, 1; starvation (snakes), 3; killed because of arthritis, 1, and of senile debility, 1; accidents (killed by animals, etc.), 32; no cause found (only viscera examined in most cases), 12.

Animals on hand July 1, 1912_____ 1,551
Accessions during the year_____ 331

  Total _____ 1,882
Deduct loss (by exchange, death, return of animals, etc.) _____ 414

  On hand June 30, 1913_____ 1,468

Class.	Species.	Individ- uals.
Mammals	154	606
Birds	202	786
Reptiles	31	76
Total	387	1,468

VISITORS.

The number of visitors to the park during the year, as deter-
mined by count and estimate, was 633,526, a daily average of 1,731.
This was nearly 100,000 more than during the fiscal year 1912. The
largest number in any one month was 120,908, in March, 1913, an
average per day of 3,900.

During the year 142 classes, schools, etc., with a total of 5,579
pupils, visited the park, a monthly average of 465. These were
mainly from the District of Columbia and neighboring States, but
other States, from Vermont, New Hampshire, and Massachusetts,
to Tennessee and South Carolina, were represented, and " Corn
Growers " belonging to 18 States.

IMPROVEMENTS.

The construction of a house for the storage and preparation of
food, which was begun toward the close of the previous year, was
completed early in this year and equipped with a large range for
cooking and baking, a small cold-storage room, dumb-waiter, etc.
The total cost of building and equipment was $3,615, of which
$3,050 was paid from this year's appropriation. The building is of
stone, 24 feet wide and 40 feet long, and has one story and a basement,
both with concrete floors. It is abundantly lighted and thoroughly
sanitary. It is located at the rear of the temporary bird house, so
that the building and the yard about it are screened from public view,
while still convenient of access. This improvement had been much
needed, as the only place previously available for the preparation of
food was the cellar of the lion house, where both light and ventila-
tion were far from satisfactory.

An inclosure and shelter house were built between the lion house
and the small-mammal house to afford temporary quarters for the
small flock of ostriches recently acquired. The house is 16 feet

wide and 24 feet long, and the adjoining inclosure, which is nearly circular, is about 100 feet in diameter.

A new inclosure, with a pool, for wood ducks and nearly related species, was built in the valley near the flying cage.

The suspension footbridge across Rock Creek near the northern entrance to the park having become unsafe, a new bridge of similar construction was built there.

A bridle path was laid out near the bank of the creek throughout its entire length in the park, and a rustic walk, mainly parallel to the roadway, was built from the concrete bridge to the north entrance.

Early in the year the first section of a retaining wall was built in the ravine opposite the point at which Ontario Road reaches the park, and later a second section was built above this, giving the wall a total height of 18 feet.

A small retaining wall was built, also, at the mouth of the little run at the northern edge of the park near Klingle Road to prevent further erosion there and protect valuable forest trees which are being undermined.

A small amount of riprapping was done at three places on the banks of the creek.

Just before the close of the year work was begun on the old elephant barn to fit it and the adjoining yard, then occupied by tapirs, for the temporary accommodation of the two young African elephants which had been secured from the zoological garden at Giza. A new yard, with a pool, for the tapirs was built next to the new elephant house, the work on this being well under way at the close of the year.

The cost of these improvements was as follows:

Food house (from 1913 appropriation)	$3, 050
Inclosure and shelter for ostriches	450
Inclosure and pool for wood ducks	200
New suspension footbridge	400
Bridle path and rustic walk	775
Retaining wall at Ontario Road	425
Retaining wall near Klingle Road	175
Riprapping banks of creek	275
Alterations of old elephant barn and inclosure	850
Total	6, 600

Through the generosity of Mr. John B. Henderson, jr., there was completed in the autumn of 1912 an outdoor cage for parrots which had heretofore been confined in the bird house. The cage is 24 by 40 feet, and about 26 feet high, has a steel framework and is covered with strong wire netting of special construction. Several species of cockatoos and macaws, and one species of Amazon parrot, in all 28 specimens, were placed in the cage, and, with few exceptions, have been thrifty and appear to enjoy their outdoor freedom.

MAINTENANCE OF BUILDINGS, INCLOSURES, ETC.

It was necessary to make quite extensive repairs during the year, so that the expenditures for upkeep were somewhat larger than usual. New concrete floors were laid in two of the largest bear yards, and the pools rebuilt. The concrete base of the partitions between the several yards was also built up sufficiently to bring the metal work of the partitions above the damp floor.

A section of the boundary fence of the park was largely rebuilt and other portions repaired, and much of the metal work of cages and inclosures was repainted, including the flying cage and eagle cage, bear yards, antelope yards, and the outside cages of the small-mammal house.

NEW BRIDGE ACROSS ROCK CREEK.

The sundry civil act for the fiscal year ending June 30, 1913, contained the following item: "For the construction of a rough-stone faced or bowlder bridge across Rock Creek to replace the present log bridge on the line of the roadway from Adams Mill Road entrance and Cathedral Avenue, $20,000." The act also includes the following provisions: "Hereafter all plans and specifications for the construction of buildings in the National Zoological Park shall be prepared under the supervision of the municipal architect of the District of Columbia, and all plans and specifications for bridges in said park shall be prepared under the supervision of the engineer of bridges of the District of Columbia."

In accordance with this requirement the matter of preparing plans and specifications for the bridge was taken up with the engineer of bridges very soon after the sundry civil act was approved (August 24, 1912). A considerable amount of preliminary work had already been done when the engineer of bridges died. The matter was taken up again with his successor and plans and specifications were prepared and advertisements made for proposals April 28, 1913. A contract for the construction of the bridge was entered into May 29, 1913. The old bridge was removed as soon as possible, and work on the new bridge was begun about the middle of June. The bridge is to be of reinforced concrete, faced with rough blocks of the blue gneiss found in this region. Stone for the concrete is to be obtained in the park. The span of the bridge is to be 80 feet and the total length at the road level 114 feet. The bridge will be 39 feet 6 inches wide from outside to outside, with a width of 36 feet 6 inches between the parapets. There will be a macadam roadway with concrete sidewalk on either side, but the construction of roadway and sidewalks will be deferred until the earth fill has thoroughly settled. The work on the main portion of the bridge covered by the contract will amount to about $10,800, while the cost of material furnished by the park, prep-

aration of plans, superintendence, and other expenses will probably bring the total cost up to $15,300. The appropriation, therefore, will be sufficient to add wing walls if desirable, and to complete the approaches. It is expected that all work under the contract will be finished and the temporary roadway built in time to open the bridge for use by October 30. It has been necessary to close the road to vehicles during the construction of the bridge.

Most of the members of the old log bridge, which was erected in 1896, were found to be in surprisingly good condition, but it was so much decayed at some vital points as to be dangerous for use.

ALTERATION OF THE WEST BOUNDARY OF THE PARK.

In the last annual report, as in several previous reports, attention was called to the urgent need of acquiring additional land along the western side of the park and the great desirability of extending the park to Connecticut Avenue. The matter was presented to Congress and an appropriation has been made for the purchase of the privately owned land lying between the western boundary of the park and Connecticut Avenue from Cathedral Avenue to Klingle Road, the land in the included highways also to become a part of the park. The land to be purchased amounts to about ten and two-thirds acres and that in the highways to about two and two-thirds acres.

Respectfully submitted.

FRANK BAKER, *Superintendent.*

Dr. CHARLES D. WALCOTT,
   Secretary of the Smithsonian Institution,
      Washington, D. C.

REPORT ON THE ASTROPHYSICAL OBSERVATORY.

Sir: I have the honor to present the following report on the operations of the Smithsonian Astrophysical Observatory for the year ending June 30, 1913:

EQUIPMENT.

The equipment of the observatory is as follows:

(a) At Washington there is an inclosure of about 16,000 square feet, containing five small frame buildings used for observing and computing purposes, three movable frame shelters covering several out-of-door pieces of apparatus, and also one small brick building containing a storage battery and electrical distribution apparatus.

(b) At Mount Wilson, Cal., upon a leased plot of ground 100 feet square, in horizontal projection, are located a one-story cement observing structure, designed especially for solar-constant measurements, and also a little frame cottage, 21 feet by 25 feet, for observer's quarters.

During the year there was erected upon the observing shelter at Mount Wilson a tower 40 feet high above the 12-foot piers which had been prepared in the original construction of the building. This tower is now being equipped as a tower telescope for use when observing (with the spectrobolometer) the distribution of radiation over the sun's disk. The cost of the tower and its apparatus has thus far been about $1,400.

Other pieces of apparatus for research have been purchased or constructed at the observatory shop. The value of these additions to the instrumental equipment, not counting the tower above mentioned and its equipment, is estimated at $1,500.

WORK OF THE YEAR.

1. ON THE SOLAR CONSTANT OF RADIATION.

When Volume II of the Annals of the Astrophysical Observatory was published in 1908 the standard scale of measurement of solar radiation had not yet been established. Several supposedly standard pyrheliometers for the purpose of fixing the true scale of radiation measurement were constructed and tried at this observatory, as men-

tioned in former reports. The results obtained agreed closely together and were checked by observations with known quantities of heat. In October, 1912, another type of standard pyrheliometer, which we called the water-stir pyrheliometer, was devised, constructed, and used. It proves to give values for the standard scale of radiation almost identical with those which we had before obtained, and in this instrument, as in the others, known test quantities of heat were introduced and measured within less than 1 per cent. In view of all these experiments with standard pyrheliometers, it is now felt that the standard scale of radiation is at length fully established. Accordingly, a publication entitled " Smithsonian Pyrheliometry Revised " was issued February 1, 1913, giving the results of all the definitive experiments on the standard scale of radiation and also the experiments made to fix the scales of all the secondary pyrheliometers in use at the Astrophysical Observatory or furnished by the Smithsonian Institution to observers in this country and abroad.

A small correction in the determinations of the solar constant of radiation made at Mount Wilson and elsewhere was found to be required owing to a residual effect of water vapor in the atmosphere which had not been entirely eliminated. This correction sometimes reaches as great a magnitude as 2 per cent. It has now been applied to all the measurements made at the various stations which have been occupied since 1902, and all the solar-constant measurements, about 700 in number, have been reduced to the new standard scale of pyrheliometry.

The mean value of the solar constant of radiation at the earth's mean distance from the sun from about 700 measurements, some at Washington, others at Mount Wilson, others at Bassour, Algeria, and still others at Mount Whitney, Cal., and covering the years from 1902 to 1912, has now been taken. *It is 1.932 calories per square centimeter per minute.*

2. THE VARIABILITY OF THE SUN.

(a) *Attending sun spots.*

In connection with the reduction of the measurements of the solar constant of radiation mentioned above, mean values were taken for each month during which observations had been made at Mount Wilson. These monthly mean values, extending from the year 1905 to the year 1912, have been compared with the so-called Wolff sun-spot numbers for the same months. The result shows, as indicated in the accompanying illustration, that increased solar-constant values attend increased sun-spot numbers. An increase of radiation at the earth's mean distance from the sun of 0.07 calorie per square

centimeter per minute appears to attend an increased spottedness of the sun represented by 100 Wolff sun-spot numbers.

(*b*) *Short interval irregular variability.*

The observations which had been begun in the year 1911 and continued in the year 1912 at Bassour, Algeria, simultaneously with similar observations at Mount Wilson, Cal., were concluded in September, 1912. The observations obtained at the two stations have

BASSOUR VALUES. CALORIES.
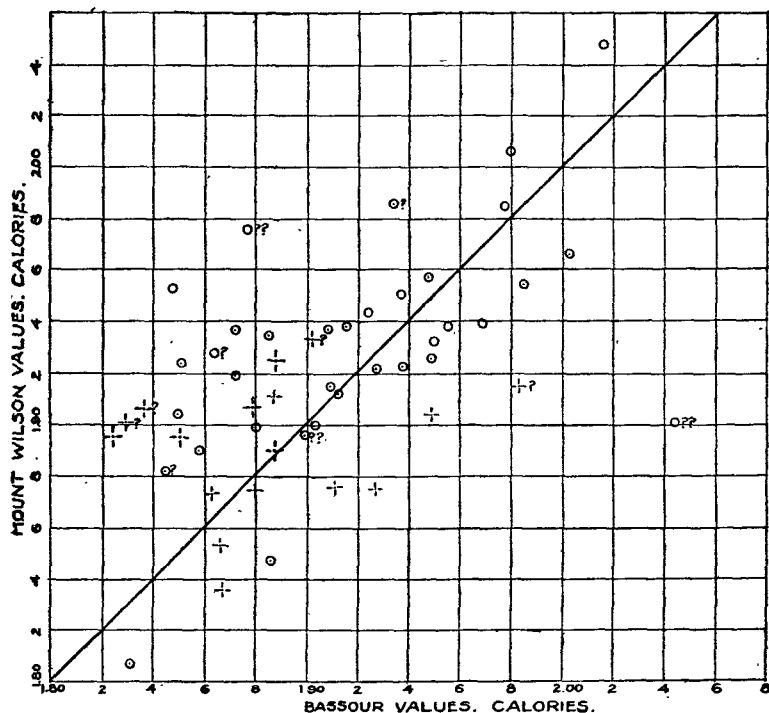
now been completely reduced and compared. The results given in the accompanying diagram show conclusively that if high values of the solar radiation (outside the atmosphere) are found from California observations, the values found from Algerian observations will be high also, and vice versa. In other words, the fluctuation of the "solar-constant" values which had been found in California in former years are now shown to be no local phenomenon due, perhaps, to atmospheric disturbances, but rather a phenomenon which is general over the earth's surface and which must be attributed to causes outside the earth altogether. It would be conceivable that such a cause might be the interposition of meteoric dust or other matter between the earth and the sun; but other evidence, which is more fully explained in Volume III of the Annals of the Astro-

physical Observatory, shows that we must attribute the changes to the sun itself and not to the interposition of matter between the earth and the sun. Thus we may conclude that the sun is variable, having not only a periodicity connected with the periodicity of sun spots, but also an irregular, nonperiodic variation, sometimes running its course in a week or 10 days, at other times in longer periods, and ranging over irregular fluctuations of from 2 to 10 per cent of the total radiation in magnitude.
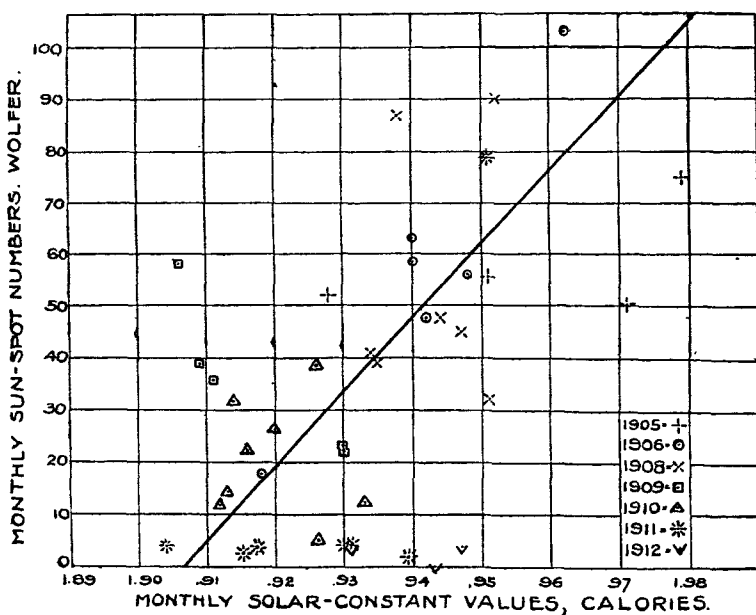
3. THE EFFECTS OF VOLCANIC ERUPTIONS.

Violent eruption of Mount Katmai, Alaska, occurred on June 6, 7, and 8, 1912. The solar observations made at Bassour, Algeria, and at Mount Wilson, Cal., began to indicate the presence of dust in the upper air from this volcano about June 20, 1912. The effects of this dust became more and more considerable, so that in August the direct radiation of the sun was reduced by the interposition of the dust cloud by about 20 per cent, both at Bassour and Mount Wilson. A study of the influence of Mount Katmai and other volcanic eruptions was published by Messrs. Abbot and Fowle in the Smithsonian Miscellaneous Collections, volume 60, No. 29, 1913. It was shown that not only the volcano of Mount Katmai, but also other great eruptions of former years, have materially decreased the direct radiation of the sun, and apparently altered the temperature of the earth. Various observers have shown that the presence of sun spots is attended with a decreased terrestrial temperature. In the paper just mentioned it is shown that quite as important an

influence is attributable to the presence of volcanic haze; and that a combination of the effects of sun spots and volcanic haze accounts for all the principal outstanding irregularities in the temperature of the earth for the last 30 years.

4. VOLUME III OF THE ANNALS OF THE ASTROPHYSICAL OBSERVATORY.

The principal work of the year was the reduction of observations and the preparation for publication of Volume III of the Annals of the Astrophysical Observatory. (Quarto; pp. XI+241; tables, 70; inserted plates, 7; text figures, 32.) The manuscript was forwarded to the Public Printer on April 1, and the first completed copy of the book was received on July 3, 1913. About 1,400 copies have been distributed to libraries and individuals throughout the world.

In brief, the experiments described therein, which include the work of the observatory from 1907 to 1913, appear—

(*a*) To have established the scale of measurement of radiation to within 1 per cent.

(*b*) To have established the solar constant of radiation to within 1 per cent.

(*c*) To have shown by two independent methods that the sun's emission is not uniform but varies with an irregular periodicity of from 7 to 10 days on the average and with irregular amounts seldom if ever exceeding 10 per cent.

(*d*) To have shown that the sun also varies in connection with the sun-spot cycle. The solar emission appears to be increased at the earth's mean distance from the sun by about 0.07 of a calorie per square centimeter per minute for an increase of 100 Wolff sun-spot numbers.

(*e*) A marked effect of volcanic dust in the upper atmosphere on the radiation of the sun and on the temperature of the earth is indicated.

(*f*) Studies of the radiation of the sky, the effects of water vapor on the solar radiation, the distribution of radiation over the sun's disk, the probable temperature of the sun, and other subjects are included.

5. STUDIES OF THE TRANSMISSION OF LONG WAVE RAYS BY WATER VAPOR IN THE EARTH'S ATMOSPHERE.

Mr. Fowle's experiments on the transmission of radiation through long columns of air containing measured quantities of water vapor were temporarily discontinued owing to the need of completing the publication of Volume III of the Annals. He, however, published a paper on the quantity of water vapor found above the Mount Wilson station.[1]

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[1] Astrophysical Journal, vol. 57, p. 359, 1913.

Toward the end of the fiscal year a vacuum bolometer was prepared for use in continuing the experiments on the transmission of very long wave rays through atmospheric water vapor. It is proposed to push this work in the immediate future.

6. THE CALIFORNIA EXPEDITION.

A grant of money from the Hodgkins fund having been made by the Institution to Mr. A. K. Ångström for observations of nocturnal radiation at different altitudes, several other lines of investigation were arranged to be included in connection with these researches. In the first place measurements were proposed on the total radiation from the sky by day. For this purpose and with the aid of a small grant from the Hodgkins fund Mr. Abbot devised and tested a special sky-radiation apparatus. This instrument comprises two blackened strips of metal, which are exposed successively at the centers of two metal plates in such a way that the whole hemisphere of the sky is free to shine on the exposed blackened strip, but nothing can come from below the horizon toward the strips. Each strip is at the center of a hemispherical glass inclosure, which serves the purpose of preventing the exchange of rays of long-wave lengths (associated with the temperature of such objects) between the blackened strip and the sky. Thus the apparatus serves to measure the quantity of radiation, originally coming from the sun, which has become diffusely scattered toward the horizontal surface by the molecules and dust particles found in the atmosphere.

Secondly, in order to determine the temperature and humidity prevailing above the stations occupied by Mr. Ångström's expeditions, the Institution procured a large number of sounding balloons, and arrangements were made with the Weather Bureau for flying these balloons from Santa Catalina Island, carrying with each ascension self-recording apparatus of the Weather Bureau for measuring the temperature, pressure, and humidity of the air. Captive balloons belonging to the Weather Bureau were also arranged to be sent up at Lone Pine, Cal., and at Mount Whitney, Cal., while Mr. Ångström was occupying these two stations.

As certain writers have expressed doubt whether measurements of the solar constant of radiation made by Langley's method of high and low observations with the spectrobolometer really furnish the solar radiation values as they would be found outside our atmosphere, it seemed desirable to check these results by observing at the highest possible altitudes the actual intensity of the solar radiation. For this purpose Mr. Abbott designed a form of pyrheliometer, similar in principle to the silver-disk pyrheliometer, but which is automatic and self-recording, and can be attached to a sounding balloon, and thus carried to very great heights. Five copies

of this instrument were prepared at the observatory shops by Mr. Kramer and Mr. Abbot, and these were sent with the expedition to California. In anticipation it may be said that the five instruments were sent up on successive days, beginning July 30, 1913, and at the time of writing this report two of them have been recovered. Each of the two had a readable record of the ascension. A preliminary reduction of the results shows that, beginning at an altitude of about 6,000 meters and separated by altitude intervals of 2,000 or 3,000 meters for successive exposure, four determinations of the solar radiation were obtained in each of the ascents. The rough computation mentioned results as follows: First ascent: 1.44, 1.60, 1.70, and 1.88 calories per square centimeter per minute. Second ascent: 1.62, 1.64, 1.76, and 1.89 calories per square centimeter per minute.

These results are subject to later recomputation, but they indicate at least that our solar-constant work of 1902–1912 by high and low sun observations on homogeneous rays, according to Langley's methods, gives results of the same order of magnitude as those obtained by direct pyrheliometric observations at extremely high altitudes.

PERSONNEL.

No change has occurred in the staff of the observatory, except that Miss F. E. Frisby completed her temporary service as computer on June 30, 1913, and Mr. A. K. Ångström served as temporary bolometric assistant in Algeria from July 1, 1912, to September 30, 1912.

SUMMARY.

The work of the observatory has been uncommonly successful. Volume III of its Annals has been published, including the work of the years 1907 to 1912. The observations at Bassour, Algeria, taken in connection with those made simultaneously at Mount Wilson, Cal., have established the variability of the sun. A variability connected with the sun-spot cycle has also been shown. The mean value of the solar constant of radiation has been fixed, it is thought, within 1 per cent. From about 700 observations, extending over the time interval from 1902 to 1912 and taken at different altitudes from sea level to 4,420 meters, the mean value is 1.932 calories per square centimeter per minute. Pyrheliometers have been sent up by means of sounding balloons to very great altitudes, and preliminary results indicate that they give values of the solar radiation similar to those found by high and low sun observations on homogeneous rays.

Respectfully submitted.

C. G. ABBOT,
Director Astrophysical Observatory,
Smithsonian Institution.

Dr. CHARLES D. WALCOTT,
Secretary of the Smithsonian Institution.

APPENDIX 6.

REPORT ON THE LIBRARY.

Sir: I have the honor to submit the following report on work performed for the Smithsonian Library during the fiscal year ending June 30, 1913:

ACCESSIONS.

The accessions to the library are obtained mainly by exchange of Smithsonian publications, or by gift. During the fiscal year 1913, 33,161 packages of publications were received as exchanges and gifts, of which 29,065 packages were transmitted by mail and 4,096 through the International Exchange Service. In addition to letters written in acknowledgement of publications received in response to the requests of the Institution for exchange, some 5,000 publications were acknowledged on the regular printed forms.

The following number of accessions for the Smithsonian deposit in the Library of Congress were recorded during the year: 3,379 volumes, 1,407 parts of volumes, 5,990 pamphlets, and 450 charts; total, 11,226 publications. The numbers in the accession catalogue ran from 508,789 to 513,026, the parts of serial publications entered on the card catalogue numbered 21,081,[1] and 1,256 slips were prepared for completed volumes. The various publications sent to the Library of Congress as soon as received and entered filled 257 boxes and comprised 30,350 separate pieces, including parts of periodicals, pamphlets and complete volumes. Besides these, about 1,704 parts of serials needed to complete sets were obtained by exchange and sent to the Library of Congress separately.

As in previous years, public documents presented to the Institution were sent to the Library of Congress without being stamped or recorded. Publications of this class to the number of 9,866 were transmitted in this manner during the year.

The Smithsonian Office Library and the small collections of books maintained by the Astrophysical Observatory and the National Zoological Park received accessions amounting altogether to 573, divided as follows: Smithsonian Office, 314 volumes, 37 parts of volumes, and 19 pamphlets; Astrophysical Observatory, 90 volumes, 21 parts of volumes, and 69 pamphlets; National Zoological Park, 13 volumes and 10 pamphlets.

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[1] Only a portion of these are included in the foregoing statistics of accessions, as periodicals are not entered in the accession record until volumes are complete.

EXCHANGES.

Through correspondence, 140 new periodicals were added during the year to the great collection of scientific journals contained in the Smithsonian deposit, together with 1,704 parts needed to complete volumes in the various series.

The matter of the completion of sets in the Smithsonian deposit received special attention. Revised want lists for Belgium, Denmark, France, Germany, the Netherlands, Norway, Sweden, and Switzerland were taken up, and, so far as possible, the needed parts were supplied. These lists were additional to the regular want cards received separately from the Library of Congress. As a result of the work carried on in this direction during the year, 192 parts of 60 different publications were sent to the Library of Congress to complete sets of periodicals in the Smithsonian deposit and 1,475 missing parts needed to complete volumes of 173 different series of publications of learned societies and scientific institutions. For other divisions of the Library of Congress 37 parts of 16 sets were supplied.

In exchange for annual reports of the American Historical Association a number of publications of European historical societies were obtained for the library, as in previous years.

READING ROOM.

The rearrangement of the reading room in the Smithsonian building mentioned in last year's report was completed. Two new oak tables have been provided, a large one for readers and a smaller one with bins for periodicals. All the doors have been removed from the cases of pigeonholes for periodicals which stand against the walls and proper space made for desks and aisles. By these changes the appearance of the room has been much improved and the periodicals made more readily accessible. The latest issues of about 262 domestic and foreign scientific periodicals are now constantly at hand and are consulted by the staff of the Institution and its branches, the scientific officers of various governmental establishments in Washington, and students generally. The series of large accession books formerly kept in the reading room have been removed to the adjoining office and placed in a special case. A partial rearrangement of the contents of the room farther to the east was effected during the year for the purpose of making the encyclopedias, dictionaries, gazetteers, and other books of general reference more readily accessible. This room contains the transactions of the various academies of the world and other similar series which are constantly needed for reference by the scientific staff of the Institution.

AERONAUTICAL LIBRARY.

The Institution possesses an excellent collection of literature relating to the subject of aeronautics, which is kept in the room last mentioned. This very valuable series of publications is rich in periodicals, especially those of early date. During the year all the books were reclassified and the volumes of periodicals were collated and made ready for binding.

ART ROOM AND EMPLOYEES' LIBRARY.

No additions to the works on art contained in this room were made during the year and the arrangement remained unchanged. All works relating to other subjects than art have been eliminated, and those properly belonging in the room are in good condition and readily accessible.

No changes were made in the small collection of general literature known as the employees' library for the reasons mentioned in last year's report.

NEW STEEL BOOKSTACKS.

The estimates for the fiscal year 1914 contained an item of $40,000 for the erection of metal bookstacks in the main hall of the Smithsonian building, to contain the library of the Bureau of American Ethnology, a part of the National Museum library, together with books belonging to other branches of the Institution, and certain collections of Smithsonian books used by the scientific and administrative staff. Toward the close of the fiscal year covered by this report Congress appropriated the sum of $15,000 for beginning this work, and arrangements were immediately made to secure a design for the bookstacks. In accordance with the plan proposed, a floor space at each end of the hall measuring 50 feet by 26 feet will be devoted to the stacks, which will be arranged in three tiers and reach from the floor to the ceiling. In order to increase the shelf capacity and at the same time preserve the appearance of the hall, a series of bookcases about 8 feet high will be carried along the north and south walls, connecting with the stacks at each end. The object of this arrangement is to concentrate the various collections of books as far as practicable and at the same time to preserve the symmetry of the hall, and to leave the central portion open for exhibits and for various Smithsonian gatherings. A portion of the space will probably be needed for the preservation and display of the personal relics of James Smithson and for objects illustrating the work of the several branches of the Institution.

CATALOGUE OF SMITHSONIAN PUBLICATIONS.

A contract was entered into during the year for the preparation of a complete catalogue of the publications of the Institution and its branches in book form. It is expected that the manuscript will be finished within a few months and that means will be found to print and issue the catalogue without serious delay.

LIBRARIES OF THE GOVERNMENT BRANCHES.

United States National Museum.—In accordance with the plans approved last year, four rooms at the northeast corner of the new building of the National Museum on the ground floor (Nos. 24, 26, 27, and 28) were fitted with steel bookstacks and other library appliances of the latest design for the reception of the portion of the Museum library needed in connection with the study and classification of the natural history and other collections in that building. The three rooms on the north side of the corridor not being separated by partitions, the entire space of 107 feet by 21 feet was divided into three portions of unequal dimensions, the western portion being assigned for a general reading room, and also for the card catalogues, reference books, charging desk, etc. The middle portion, of smaller dimensions, for quiet reading; and the larger eastern portion for the general stacks. The stacks are in two tiers separated by a glass floor. In the middle room the arrangement is similar, except that a large table occupies the central floor space. A gallery which extends around three sides of the general reading room also supports stacks, and on the ground floor additional shelving occupies the east wall of this room. Open shelves for current numbers of periodicals occupy the space under the windows. Two steel manuscript cases have been placed in the middle room, and a small lift for raising books to the upper or mezzanine floor, and suitable staircases have also been provided. A special feature of the stack room is that every second stack is but $3\frac{1}{2}$ feet high instead of 7 feet. This arrangement reduces the total shelf capacity a little, but provides a place on which to lay books when they are being rearranged or used by readers. As the members of the staff and other students are permitted to consult books in the stack room, the provision is a necessary one.

The room on the south side of the corridor (No. 27) was arranged as an office for the assistant librarian and the cataloguers. Bookstacks extend around the walls of the room on three sides, and there are two additional stacks, dividing the room practically into three.

The steel stacks were completed about October 15, 1912, and the moving of books from the old quarters was begun immediately. The task of placing the books on the new shelves occupied about a month,

during which time they were, nevertheless, available for use by readers and the delivery of books to the sectional libraries was not interrupted. For moving, the books were tied together in lots of convenient size for handling, and each lot received a number. It was then a simple matter to put the books in their proper places on the shelves in the new library. After they were in place, the library was fortunately able to employ temporary assistants to go over them all for the purpose of checking up the various series and ascertaining whether the volumes were all present and in their proper sequence.

The arrangement of the cards belonging to the Zurich catalogue of scientific literature has been perfected, and they are now available for reference.

In accordance with the plans decided upon, as mentioned in last year's report, the books on museum administration, technology, history, botany, and some other subjects were allowed to remain in the old quarters, where they would be most readily accessible to the members of the staff and others working in those lines. It is the intention, however, to transfer the botanical books to the new stacks in the Smithsonian Building as soon as the latter shall have been completed.

This portion of the library was rearranged and recatalogued as rapidly as possible, and with the aid of additional help the publications had been classified on the shelves at the close of the year and about one-half of them recatalogued. The following work in this direction was accomplished during the year: Books catalogued, 1,370; pamphlets, 2,416; total number of cards made, 3,132. Completed volumes of periodicals catalogued, 2,938; parts of publications, 19.059; total number of cards made, 1,117.

During the year 881 volumes were prepared for binding and sent to the Government bindery for that purpose.

Many important gifts were received by the library during the year, and the following members of the staff presented publications: Secretary Charles D. Walcott, Dr. Theodore N. Gill, Dr. William H. Dall, Mr. Robert Ridgway, Dr. C. W. Richmond, Dr. J. C. Crawford, Dr. O. P. Hay, and Mr. W. R. Maxon.

The Museum library now contains 43,692 volumes, 72,042 unbound papers, and 122 manuscripts. The accessions during the year covered by this report consisted of 1,690 books, 2,213 pamphlets, and 159 parts of volumes. The number catalogued, exclusive of those mentioned above, was as follows: 782 books, 892 complete volumes of periodicals, and 2,229 pamphlets.

The number of books, periodicals, and pamphlets borrowed from the general library amounted to 25,846, among which were 3,888 obtained from the Library of Congress, 117 from the Department of

Agriculture, 71 from the Army Medical Museum and library, 59 from the United States Geological Survey, and 19 from other libraries. Publications to the number of 4,832 were assigned to the sectional libraries of the Museum during the year.

The following is a complete list of the sectional libraries now existing:

Administration.	Marine invertebrates.
Administrative assistant's office.	Materia medica.
Anthropology.	Mechanical technology.
Biology.	Mollusks.
Birds.	Oriental archeology.
Botany.	Paleobotany.
Comparative anatomy.	Parasites.
Editor's office.	Photography.
Ethnology.	Physical anthropology.
Fishes.	Prehistoric archeology.
Geology.	Reptiles and batrachians.
Graphic arts.	Superintendent's office.
Insects.	Taxidermy.
Invertebrate paleontology.	Textiles.
Mammals.	Vertebrate paleontology.

The records of the Museum library consist of an author's catalogue, an accession book, a periodical record on standard cards, and a lending record. This lending record is on cards and includes books borrowed from the Library of Congress and other libraries for the use of the staff.

The library is largely dependent upon the exchange of Museum publications as a means of increase. During the year many letters asking for missing parts and for new exchanges were sent out, and a number of sets were completed in this way and new publications also added to the library.

Bureau of American Ethnology.—The report on this library will be made by the ethnologist in charge and incorporated in his general report on the operations of the bureau.

Astrophysical Observatory.—The small collection of books constituting the reference library of the Astrophysical Observatory was rearranged in the cases in the main hall of the Smithsonian Building, to which they were transferred from one of the tower rooms. During the year 90 volumes, 21 parts of volumes, and 69 pamphlets were received. This collection of books will eventually be placed in the new steel stacks, for which an appropriation was made at the last session of Congress.

National Zoological Park.—A small number of books on zoological subjects are kept in the office of the superintendent of the park. During the year 13 volumes and 10 pamphlets were added.

SUMMARY OF ACCESSIONS.

The following statement summarizes all the accessions during the year, except those made to the library of the Bureau of American Ethnology:

To the Smithsonian deposit in the Library of Congress, including parts to complete sets (see p. 94)	12, 930
To the Smithsonian office, Astrophysical Observatory, and Zoological Park	573
To the United States National Museum	4, 062
Total	17, 565

Very respectfully,

F. W. TRUE,
Assistant Secretary, in charge
of Library and Exchanges.

Dr. CHARLES D. WALCOTT,
Secretary of the Smithsonian Institution.

REPORT ON THE INTERNATIONAL CATALOGUE OF SCIENTIFIC LITERATURE.

Sir: I have the honor to submit the following report on the operations of the United States Bureau of the International Catalogue of Scientific Literature for the year ending June 30, 1913.

The International Catalogue of Scientific Literature now consists of 33 regional bureaus, a new bureau representing the Argentine Republic having been recently established at the Universidad de Buenos Aires. It appears probable that Bolivia will soon also be represented by a regional bureau. The following-named countries are represented by regional bureaus supported in most cases by direct governmental grants: Argentine Republic, Austria, Belgium, Canada, Cuba, Denmark, Egypt, Finland, France, Germany, Greece, Holland, Hungary, India and Ceylon, Italy, Japan, Mexico, New South Wales, New Zealand, Norway, Poland, Portugal, Queensland, Russia, South Africa, South Australia, Spain, Straits Settlements, Sweden, Switzerland, United States of America, Victoria and Tasmania, and Western Australia.

These bureaus, acting through the London Central Bureau, form the organization of the International Catalogue of Scientific Literature, whose duty it is to collect, index, classify, and publish a current catalogue of the world's scientific literature. The London Central Bureau assembles, edits, and publishes the classified references supplied by the regional bureaus.

The enterprise was begun in 1901 and since then there have been published annually 17 volumes, one each year for the following-named branches of science: Mathematics, mechanics, physics, chemistry, astronomy, meteorology, mineralogy, geology, geography, paleontology, general biology, botany, zoology, anatomy, anthropology, physiology, and bacteriology.

All of the first 9 annual issues of the catalogue have been published, 14 volumes of the tenth issue, and 2 volumes of the eleventh, a total of 169 regular volumes in addition to several special volumes of Schedules and Lists of Journals.

The annual subscription price for a complete set of 17 volumes is $85. The receipts from the sale of the catalogue are used for the maintenance of the central bureau, which pays for editing and print-

ing the catalogue. The balance sheet for the ninth annual issue showed a credit for that issue of about $1,500 over and above expenses. This is considered a satisfactory showing in view of the fact that undertakings of this kind are in no sense commercial and can hardly be expected to meet necessary expenses without aid from an endowment or some similar source. The enterprise was begun without a working capital other than the sums advanced from time to time by the Royal Society of London. As interest is paid on all sums so advanced the financial showing is not what it would have been had the enterprise possessed a working capital. The sum needed to completely pay off all obligations and leave a substantial balance for the maintenance of the central bureau is only about $75,000, and it would be difficult to find an object more deserving of assistance and encouragement than this International Catalogue of Scientific Literature whose purpose is to aid research and investigations in scientific fields by furnishing a current classified index to the literature of science. Some idea of the extent of the work may be gained from the fact that about two and one-half million classified citations were received by the central bureau from the regional bureaus since the beginning of the enterprise in 1901, of these over 290,000 were prepared by the regional bureau of the United States.

During the year 27,995 cards were sent from this bureau to the London Central Bureau, as follows:

Literature of—

1902	9
1903	5
1904	12
1905	14
1906	131
1907	226
1908	324
1909	685
1910	3, 214
1911	6, 950
1912	16, 425
Total	27, 995

The following table shows the number of cards sent each year as well as the number of cards representing the literature of each year from 1901 to 1912, inclusive:

Literature of—	1901	1902	1903	1904	1905	1906	1907	1908	1909	1910	1911	1912	Total for year.
Year ending June 30—													
1902	6,990												6,990
1903	6,150	8,330											14,480
1904	3,044	9,424	8,745										21,213
1905	1,619	2,780	11,143	8,640									24,182
1906	301	622	3,538	12,139	9,001								25,601
1907	384	511	862	5,272	9,022	12,578							28,629
1908	408	523	366	956	5,629	7,217	13,429						28,528
1909	133	235	373	309	1,656	4,410	8,509	18,784					34,409
1910	72	173	248	465	1,163	1,502	3,160	6,305	11,994				25,082
1911	3	26	28	218	129	374	423	1,301	8,836	14,682			26,020
1912			4	243	386	562	1,480	1,949	3,372	5,231	13,974		27,201
1913		9	5	12	14	131	226	324	685	3,214	6,950	16,425	27,995
Total	19,104	22,633	25,312	28,254	27,000	26,774	27,227	28,663	24,887	23,127	20,924	16,425	290,330

Control over the catalogue is vested in a body known as the International Convention which has held two meetings in London, the last being in 1910. In the intervals between the meetings of this body the administration of the catalogue is directed by the International Council expected to meet in London once in three years and to which each country represented by a regional bureau is requested to send a representative.

Meetings of the International Council were held in 1904, 1907, and in 1909, and a meeting of the International Convention was held in 1910, so that a meeting of the International Council was planned for 1913. This meeting, by a vote of the executive committee, was postponed until 1914, as a number of new plans for the reduction of cost and increasing the efficiency of the catalogue were either just going into effect, or had been in operation but a short time, and it was felt that the later date would give the members of the council a better opportunity to judge their value.

Very respectfully,

LEONARD C. GUNNELL,
Assistant in Charge.

Dr. CHARLES D. WALCOTT,
Secretary of the Smithsonian Institution.

APPENDIX 8.

REPORT ON THE PUBLICATIONS.

SIR: I have the honor to submit the following report on the publications of the Smithsonian Institution and its branches during the year ending June 30, 1913:

The Institution proper published during the year 40 papers in the series of "Smithsonian Miscellaneous Collections," an annual report, and pamphlet copies of 37 papers from the general appendix of the report. The Bureau of American Ethnology published an annual report and 3 bulletins, and the United States National Museum issued 96 miscellaneous papers from the Proceedings, a new bulletin, reprint editions of 2 bulletins, and 9 parts of volumes pertaining to the National Herbarium.

The total number of copies of publications distributed by the Institution proper during the year was 111,283, or 1,052 more than during the previous year. This aggregate includes 600 volumes and memoirs of Smithsonian Contributions to Knowledge, 62,688 volumes and pamphlets of Smithsonian Miscellaneous Collections, 22,401 volumes and pamphlets of the Smithsonian Annual Reports, 8,787 special publications, including volume 3 of the Annals of the Astrophysical Observatory and reports on the Harriman Alaska expedition; 15,070 volumes and pamphlets of the Bureau of American Ethnology publications, 1,646 Annual Reports of the American Historical Association, 8 publications of the United States National Museum, and 83 publications not of the Smithsonian Institution or its branches. The National Museum distributed a total of 71,600 copies of its several publications.

SMITHSONIAN CONTRIBUTIONS TO KNOWLEDGE.

QUARTO.

No publications of this series were issued during the year.

SMITHSONIAN MISCELLANEOUS COLLECTIONS.

OCTAVO.

Of the Miscellaneous Collections, volume 57, 2 papers were published; of volume 58, 1 paper, and title-page and contents of the volume; of volume 59, 5 papers; of volume 60, 28 papers; of volume 61, 4 papers; in all, 40 papers. These are as follows:

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Volume 57.

No. 9. New York Potsdam-Hoyt Fauna. By Charles D. Walcott. Published September 14, 1912. 54 p., 13 pls. (Publ. 2136.)

No. 10. Group terms for lower and upper Cambrian series of formations. By Charles D. Walcott. September 16, 1912. 3 p. (Publ. 2137.)

Volume 58.

No. 2. Bibliography of the geology and mineralogy of tin. By Frank L. and Eva Hess. July 29, 1912. v, 408 p. (Publ. 1987.)

Title-pages and contents. December 31, 1912. v p. (Publ. 2160.)

Volume 59.

No. 11. Expeditions organized and participated in by the Smithsonian Institution in 1910 and 1911. July 17, 1912. 51 p., 1 pl., 56 figs. (Publ. 2087.)

No. 16. New Rodents from British East Africa. By Edmund Heller. July 5, 1912. 20 p. (Publ. 2094.)

No. 17. New Diptera from Panama. By J. R. Malloch. July 18, 1912. 8 p. (Publ. 2133.)

No. 18. New species of landshells from Panama Canal Zone. By William H. Dall. July 27, 1912. 3 p., 2 pls. (Publ. 2134.)

No. 20. The recognition of Pleistocene faunas. By Oliver P. Hay. August 17, 1912. 16 p., 10 figs. (Publ. 2139.)

Volume 60.

No. 1. Three new species of Pipunculidæ (Diptera) from Panama. By J. R. Malloch. September 6, 1912. 4 p., 3 figs. (Publ. 2141.)

No. 2. New mammals from eastern Panama. By E. A. Goldman. September 20, 1912. 18 p. (Publ. 2142.)

No. 3. Descriptions of new genera, species, and subspecies of birds from Panama, Colombia, and Ecuador. By E. W. Nelson. September 27, 1912. 25 p. (Publ. 2143.)

No. 4. Rubelzul cotton: A new species of Gossypium from Guatemala. By Frederick L. Lewton. October 21, 1912. 2 p., 2 pls. (Publ. 2144.)

No. 5. Kokia: A new genus of Hawaiian trees. By Frederick L. Lewton. October 22, 1912. 4 p., 5 pls. (Publ. 2145.)

No. 6. The cotton of the Hopi Indians: A new species of Gossypium. By Frederick L. Lewton. October 23, 1912. 10 p., 5 pls. (Publ. 2146.)

No. 7. Descriptions of one hundred and four new species and subspecies of birds from the Barussan Islands and Sumatra. By Harry C. Oberholser. October 26, 1912. 22 p. (Publ. 2147.)

No. 8. New genera and races of African ungulates. By Edmund Heller. November 2, 1912. 16 p. (Publ. 2148.)

No. 9. A recent meteorite fall near Holbrook, Navajo County, Arizona. By George P. Merrill. November 21, 1912. 4 p. (Publ. 2149.)

No. 10. The crinoids of the Natural History Musuem at Hamburg. By Austin Hobart Clark. November 7, 1912. 33 p. (Publ. 2150.)

No. 11. A fossil toothed cetacean from California, representing a new genus and species. By Frederick W. True. November 1, 1912. 7 p., 2 pls. (Publ. 2151.)

No. 12. New races of insectivores, bats, and lemurs from British East Africa. By Edmund Heller. November 4, 1912. 13 p. (Publ. 2152.)

No. 13. A study of the salinity of the surface water in the North Pacific Ocean and the adjacent enclosed seas. By Austin Hobart Clark. December 4, 1912. 33 p. (Publ. 2153.)

No. 14. New mammals from the highlands of Siberia. By N. Hollister. November 29, 1912. 6 p. (Publ. 2157.)

No. 15. A new subspecies of crossbill from Newfoundland. By A. C. Bent. December 12, 1912. 3 p. (Publ. 2158.)

No. 16. Remains in Eastern Asia of the race that peopled America. By Aleš Hrdlička. December 31, 1912. 5 p., 3 pls. (Publ. 2159.)

No. 17. Notes on American species of Peripatus, with a list of known forms. By Austin Hobart Clark. January 25, 1913. 5 p. (Publ. 2163.)

No. 18. Smithsonian pyrheliometry revised. By C. G. Abbot and L. B. Aldrich. February 1, 1913. 7 p. (Publ. 2164.)

No. 19. Description of a new gazelle from northwestern Mongolia. By N. Hollister. February 8, 1913. 2 p. (Publ. 2165.)

No. 20. Description of a new African grass-warbler of the genus Cisticola. By Edgar A. Mearns. February 14, 1913. 2 p. (Publ. 2166.)

No. 21. Two new subspecies of birds from the slopes of Mount Pirri, eastern Panama. By E. W. Nelson. February 26, 1913. 2 p. (Publ. 2167.)

No. 22. Descriptions of new mammals from Panama and Mexico. By E. A. Goldman. February 28, 1913. 20 p. (Publ. 2168.)

No. 24. Two new mammals from the Siberian Altai. By N. Hollister. March 13, 1913. 3 p. (Publ. 2171.)

No. 25. Diagnosis of a new beaked whale of the genus Mesoplodon from the coast of North Carolina. By Frederick W. True. March 14, 1913. 2 p. (Publ. 2172.)

No. 26. Notice of the occurrence of a Pleistocene camel north of the Arctic Circle. By James Williams Gidley. March 21, 1913. 2 p. (Publ. 2173.)

No. 27. An extinct American eland. By James Williams Gidley. March 22, 1913. 3 p., 1 pl. (Publ. 2174.)

No. 28. A new vole from eastern Mongolia. By Gerrit S. Miller, jr. March 31, 1913. 2 p., 1 pl. (Publ. 2175.)

No. 29. Volcanoes and climate. By C. G. Abbot and F. E. Fowle. March 28, 1913. 24 p., 3 figs. (Publ. 2176.)

Volume 61.

No. 2. Description of the skull of an extinct horse, found in central Alaska. By Oliver P. Hay. June 4, 1913. 18 p., 2 pls. (Publ. 2181.)

No. 3. Report on fresh-water Copepoda from Panama, with descriptions of new species. By C. Dwight Marsh. June 20, 1913. 30 p., 5 pls. (Publ. 2182.)

No. 4. Saffordia, a new genus of ferns from Peru. By William R. Maxon. May 26, 1913. 5 p., 2 pls., 1 fig. (Publ. 2183.)

No. 5. A new dinosaur from the lance formation of Wyoming. By Charles W. Gilmore. May 24, 1913. 5 p., 5 figs. (Publ. 2184.)

The following papers of the Smithsonian Miscellaneous Collections were in press at the close of the fiscal year:

Volume 57.

No. 11. Cambrian geology and paleontology. II. New Lower Cambrian subfauna. By Charles D. Walcott. 309–326 p., 50–54 pls. (Publ. 2185.)

No. 12. Cambrian geology and paleontology. II. Cambrian formations of the Robson Peak district, British Columbia and Alberta, Canada. By Charles D. Walcott. 327–343 p., 55–59 pls. (Publ. 2186.)

No. 13. Cambrian geology and paleontology. II. Dikelocephalus and other genera of the Dikelocephalinæ. By Charles D. Walcott. 345–408 p., 60–70 pls. (Publ. 2187.)

Volume 59.

No. 19. Early Norse Visits to North America. By William H. Babcock. iii, 213 p., 10 pls. (Publ. 2138.)

Volume 60.

No. 23. The influence of the atmosphere on our health and comfort in confined and crowded places. By Leonard Hill, Martin Flack, James McIntosh, R. A. Rowlands, and H. B. Walker. Hodgkins Fund. 96 p. (Publ. 2170.)

No. 30. Explorations and field-work of the Smithsonian Institution in 1912. 76 p., 82 figs. (End of volume.) (Publ. 2178.)

Volume 61.

No. 1. The White Rhinoceros. By Edmund Heller. 77 p., 31 pls. (Publ. 2180.)

SMITHSONIAN ANNUAL REPORTS.

Report for 1911.

The Annual Report of the Board of Regents for 1911 was received from the Public Printer in completed form in January, 1913.

Annual Report of the Board of Regents of the Smithsonian Institution, showing operations, expenditures, and conditions of the Institution for the year ending June 30, 1911. xii, 688 p., 97 pls. (Publ. 2095.)

Small editions of the following papers, forming the general appendix of the annual report for 1911, were issued in pamphlet form:

The gyrostatic compass. By H. Marchand. 5 p., 3 pl. (Publ. 2096.)

Radiotelegraphy. By G. Marconi. 15 p., 1 pl. (Publ. 2097.)

Multiplex telephony and telegraphy by means of electric waves guided by wires. By George O. Squier. 21 p., 1 pl. (Publ. 2098.)

Recent experiments with invisible light. By R. W. Wood. 12 p., 6 pls. (Publ. 2099.)

What electrochemistry is accomplishing. By Joseph W. Richards. 16 p. (Publ. 2100.)

Ancient and modern views regarding the chemical elements. By William Ramsay. 15 p. (Publ. 2101.)

The fundamental properties of the elements. By Theodore William Richards. 17 p. (Publ. 2102.)

The production and identification of artificial precious stones. By Noel Heaton. 18 p., 3 pls. (Publ. 2103.)

The sterilization of drinking water by ultra-violet radiations. By Jules Courmont. 11 p. (Publ. 2104.)

The legal time in various countries. By M. Philippot. 8 p. Map. (Publ. 2105.)

Some recent interesting developments in astronomy. By J. S. Plaskett. 16 p. (Publ. 2106.)

The age of the earth. By J. Joly. 23 p. (Publ. 2107.)

International air map and aeronautical marks. By Ch. Lallemand. 8 p. (Publ. 2108.)

Geologic work of ants in tropical America. By J. C. Branner. 31 p., 1 pl. (Publ. 2109.)

On the value of the fossil floras of the arctic regions as evidence of geological climates. By A. G. Nathorst. 10 p. (Publ. 2110.)

Recent advances in our knowledge of the production of light by living organisms. By F. Alex. McDermott. 18 p. (Publ. 2111.)

Organic evolution; Darwinian and de Vriesian. By N. C. Macnamara. 16 p. (Publ. 2112.)

Magnalia naturæ; or the greater problems of biology. By D'Arcy Wentworth Thompson. 15 p. (Publ. 2113.)

A history of certain great horned owls. By Charles R. Keyes. 11 p. 8 pls. (Publ. 2114.)

The passenger pigeon. By Pehr Kalm (1759) and John James Audubon (1831). 18 p., 1 pl. (Publ. 2115.)

Note on the iridescent colors of birds and insects. By A. Mallock. 8 p., 3 pls. (Publ. 2116.)

On the positions assumed by birds in flight. By Bentley Beetham. 7 p., 8 pls. (Publ. 2117.)

The garden of serpents. Butantan, Brazil. By S. Pozzi. 6 p. (Publ. 2118.)

Some useful native plants from New Mexico. By Paul C. Standley. 16 p., 13 pls. (Publ. 2119.)

The tree ferns of North America. By William R. Maxon. 29 p., 15 pls. (Publ. 2120.)

The value of ancient Mexican manuscripts in the study of the general development of writing. By Alfred M. Tozzer. 14 p., 5 pls. (Publ. 2121.)

The discoverers of the art of iron manufacture. By W. Belck. 15 p. (Publ. 2122.)

The Kabyles of north Africa. By A. Lissauer. 16 p., 12 pls. (Publ. 2123.)

Chinese architecture and its relation to Chinese culture. By Ernst Boerschmann. 29 p., 10 pls. (Publ. 2124.)

The Lolos of Kientchang, western China By A. F. Legendre. 18 p., 4 pls. (Publ. 2125.)

The physiology of sleep. By R. Legendre. 16 p. (Publ. 2126.)

Profitable and fruitless lines of endeavor in public health work. By Edwin O. Jordan. 8 p. (Publ. 2127.)

Factory sanitation and efficiency. By C.-E. A. Winslow. 6 p. (Publ. 2128.)

The physiological influence of ozone. By Leonard Hill and Martin Flack. 12 p. (Publ. 2129.)

Traveling at high speeds on the surface of the earth and above it. By H. S. Hele-Shaw. 21 p. (Publ. 2130.)

Robert Koch, 1843–1910. By C. J. M. 8 p., 1 pl. (Publ. 2131.)

Sir Joseph Dalton Hooker, 1817–1911. By Lieut. Col. D. Prain. 13 p., 1 pl. (Publ. 2132.)

Report for 1912.

The report of the executive committee and proceedings of the Board of Regents of the Institution, as well as the report of the Secretary for the fiscal year ending June 30, 1912, both forming part

of the annual report of the Board of Regents to Congress, were published in pamphlet form in December, 1912, as follows:

Report of the executive committee and Proceedings of the Board of Regents for the year ending June 30, 1912. 22 pp. (Publ. 2155.)

Report of the secretary of the Smithsonian Institution for the year ending June 30, 1912. iii, 110 p., 2 pl. (Publ. 2156.)

The general appendix to the Smithsonian Report for 1912 was in type, but actual presswork was not completed at the close of the fiscal year. In the general appendix are the following papers:

The year's progress in astronomy, by P. Puiseux.

The spiral nebulæ, by P. Puiseux.

The radiation of the sun, by C. G. Abbot.

Molecular theories and mathematics, by Émile Borel.

Modern mathematical research, by G. A. Miller.

The connection between the ether and matter, by Henri Poincaré.

Experiments with soap bubbles, by C. V. Boys.

Measurements of infinitestimal quantities of substances, by William Ramsay.

The latest achievements and problems of the chemical industry, by Carl Duisberg.

Holes in the air, by W. J. Humphreys.

Review of applied mechanics, by L. Lecornu.

Report on the recent great eruption of the volcano " Stromboli," by Frank A. Perret.

The glacial and postglacial lakes of the Great Lakes region, by Frank B. Taylor.

Applied geology, by Alfred H. Brooks.

The relations of paleobotany to geology, by F. H. Knowlton.

Geophysical research, by Arthur L. Day.

A trip to Madagascar, the country of beryls, by A. Lacroix.

The fluctuating climate of North America, by Ellsworth Huntington.

The survival of organs and the " culture " of living tissues, by R. Legendre.

Adaptation and inheritance in the light of modern experimental investigation, by Paul Kammerer.

The paleogeographical relations of antarctica, by Charles Hedley.

The ants and their guests, by P. E. Wasmann.

The penguins of the antarctic regions, by L. Gain.

The derivation of the European domestic animals, by C. Keller.

Life: its nature, origin, and maintenance, by E. A. Schäfer.

The origin of life: a chemist's fantasy, by H. E. Armstrong.

The appearance of life on worlds and the hypothesis of Arrhénius, by Alphonse Berget.

The evolution of man, by G. Elliot Smith.

The history and varieties of human speech, by Edward Sapir.

Ancient Greece and its slave population, by S. Zaborowski.

Origin and evolution of the blond Europeans, by Adolphe Bloch.

History of the finger-print system, by Berthold Laufer.

Urbanism: A historic, geographic, and economic study, by Pierre Clerget.

The Sinai problem, by E. Oberhummer.

The music of primitive peoples and the beginnings of European music, by Willy Pastor.

Expedition to the South Pole, by Roald Amundsen.

Icebergs and their location in navigation, by Howard T. Barnes.

Henri Poincaré, his scientific work, his philosophy, by Charles Nordmann.

SPECIAL PUBLICATIONS.

The following special publications were issued in octavo form:

Publication lists.

Classified list of Smithsonian publications available for distribution January 1, 1913. Published February 25, 1913. vi, 31 p. (Publ. 2161.)

Publications of the Smithsonian Institution issued between January 1 and July 1, 1912. July 19, 1912. 2 p. (Publ. 2135.)

Publications of the Smithsonian Institution issued between January 1 and October 1, 1912. October 28, 1912. 3 p. (Publ. 2154.)

Publications of the Smithsonian Institution issued between January 1 and December 31, 1912. February 1, 1913. 5 p. (Publ. 2162.)

Publications of the Smithsonian Institution issued between January 1 and March 31, 1913. April 10, 1913. 1 p. (Publ. 2179.)

Zoological nomenclature.

Opinions rendered by the International Commission on Zoological Nomenclature, Opinions 52–56. May 10, 1913. 12 p. (Publ. 2169.)

The following special publication was in press at the close of the fiscal year:

Harriman Alaska series.

Vol. 14. Monograph of Shallow-water Starfishes of the North Pacific Coast from the Arctic Ocean to California. By Addison Emery Verrill. xii, 338 p., 110 pl. (Publ. 2140.)

PUBLICATIONS OF THE UNITED STATES NATIONAL MUSEUM.

The publications of the National Museum are: (*a*) The annual report to Congress; (*b*) the proceedings of the United States National Museum, and (*c*) the bulletin of the United States National Museum, which includes the contributions from the United States National Herbarium. The editorship of these publications is vested in Dr. Marcus Benjamin.

The publications issued by the National Museum during the year comprised 96 papers of the Proceedings, 2 bulletins, and 9 parts of Contributions from the National Herbarium.

The issues of Proceedings were as follows: Vol. 42, papers 1907 to 1922, inclusive; Vol. 43, papers 1923 to 1945, inclusive; Vol. 44, papers 1946 to 1975, inclusive; Vol. 45, papers 1977, 1978, 1979, 1980, 1981, 1982, 1983, 1984, 1986, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, and 2004; a total of 96 papers.

The bulletins were as follows:

Bulletin 79. List of North American Land Mammals in the United States National Museum, 1911. By Gerrit S. Miller, jr.

Bulletin 81. Synopsis of the Rotatoria. By Harry K. Harring.

In the series of Contributions from the National Herbarium (octavo) there appeared:

Volume 16.

Part 3. The North American species of Nymphaea. By Gerrit S. Miller, jr., and Paul C. Standley.

Part 4. Descriptions of new plants preliminary to a report upon the flora of New Mexico. By E. O. Wooton and Paul C. Standley.

Part 5. Miscellaneous Papers. By C. V. Piper, J. N. Rose, Paul C. Standley, W. E. Safford, and E. S. Steele.

Part 6. Three new genera of stilt palms (Iriarteaceæ) from Colombia, with a synoptical review of the family. By O. F. Cook and C. B. Doyle.

Part 7. Studies in Cactaceæ. Part 1. By N. L. Britton and J. N. Rose.

Part 8. Relationships of the false date palm of the Florida Keys, with a synoptical key to the families of American palms. By O. F. Cook.

Part 9. The genus Epiphyllum and its allies. By N. L. Britton and J. N. Rose.

Volume 17.

Part 1. The lichen flora of southern California. By Hermann Edward Hasse.

Part 2. Studies of tropical American ferns. No. 4. By William R. Maxon.

There was also reprinted an edition of 500 copies of Bulletin 71, Part 2, A monograph of the Foraminifera of the North Pacific Ocean. Part II. Textulariidæ, by Joseph A. Cushman; and an edition of 100 reprints of Bulletin 79, List of North American Land Mammals in the United States National Museum, 1911, by Gerrit S. Miller, jr.

Among the National Museum publications in press at the close of the year were: Bulletin 80, A descriptive account of the building recently erected for the departments of natural history of the United States National Museum, by Richard Rathbun. 131 p., 34 pl., and the annual report for 1912.

PUBLICATIONS OF THE BUREAU OF AMERICAN ETHNOLOGY.

The publications of the bureau are discussed elsewhere in the Secretary's report. The editorial work is in the charge of Mr. J. G. Gurley.

One annual report and two new bulletins, together with a partially revised edition of a third bulletin, were issued during the year, as follows:

Twenty-eighth Annual Report, containing ("Accompanying Papers," as follows: (1) Casa Grande, by Jesse Walter Fewkes; (2) Antiquities of the Upper Verde River and Walnut Creek Valleys, Arizona, by Jesse Walter Fewkes; (3) Preliminary Report on the Linguistic Classification of Algonquian Tribes, by Truman Michelson.)

Bulletin 30. Handbook of American Indians North of Mexico, edited by Frederick Webb Hodge. [By concurrent resolution of Congress in August, 1912, a reprint of this bulletin was ordered in an edition of 6,500 copies, of which 4,000 were for the use of the House of Representatives, 2,000 for the use of the Senate, and 500 for the use of the bureau. This reprint, in which were incorporated such desirable alterations as could be conveniently made without affecting the pagination of the work, was issued in January, 1913.]

Bulletin 52. Early Man in South America. By Aleš Hrdlička in collaboration with William H. Holmes, Bailey Willis, Fred. Eugene Wright, and Clarence N. Fenner.

Bulletin 54. The Physiography of the Rio Grande Valley, New Mexico, in Relation to Pueblo Culture. By Edgar Lee Hewett, Junius Henderson, and Wilfred William Robbins.

The Twenty-ninth Annual Report ("Accompanying Paper," The Ethnogeography of the Tewa Indians, by John Peabody Harrington) was in press at the close of the year.

PUBLICATIONS OF THE SMITHSONIAN ASTROPHYSICAL OBSERVATORY.

Volume III of the Annals of the Smithsonian Astrophysical Observatory was printed and nearly ready for distribution at the close of the fiscal year.

PUBLICATIONS OF THE AMERICAN HISTORICAL ASSOCIATION.

The annual reports of the American Historical Association are transmitted by the association to the Secretary of the Smithsonian Institution, and are communicated to Congress under the provisions of the act of incorporation of the association.

The annual report for 1910 was published October 22, 1912, with contents as follows:

Report of the proceedings of the twenty-sixth annual meeting of the American Historical Association. By Waldo G. Leland, secretary.

Report of the proceedings of the seventh annual meeting of the Pacific coast branch. By Jacob N. Bowman, secretary of the branch.

The efforts of the Danish Kings to secure the English crown after the death of Harthacnut. By Laurence M. Larson.

The records of the privy seal. By James F. Baldwin.

Royal purveyance in fourteenth-century England in the light of Simon Islip's Speculum Regis. By Chalfant Robinson.

Anglo-Dutch relations, 1654–1660. By Ralph C. H. Catterall.

Some critical notes on the works of S. R. Gardiner. By Roland G. Usher.

The Mexican policy of southern leaders under Buchanan's administration. By James Morton Callahan.

The decision of the Ohio Valley. By Carl Russell Fish.

North Carolina on the eve of secession. By William K. Boyd.

The inception of the Montgomery convention. By Armand J. Gerson.

The attitude of Congress toward the Pacific Railway, 1856–1862. By Allen Marshall Kline.

The work of the Western State Historical Society, as illustrated by Nevada. By Jeanne E. Wier.

Proceedings of the seventh annual conference of historical societies.

The study of history in secondary schools. Report of the Committee of Five.

Eleventh annual report of the public archives commission. By Herman V. Ames, chairman.

Appendix A. Proceedings of the second annual conference of archivists.

Appendix B. Report on the archives of the State of Indiana. By Harlow Lindley.

Appendix C. Report on the archives of the State of Kentucky. By Irene T. Myers.

Appendix D. Report on the archives of the State of Nebraska. By Addison E. Sheldon.

Appendix E. Notes on the archives of the Philippines. By James A. Robertson.

Writings on American History, 1910. By Grace G. Griffin.

The report for 1911, in two volumes, was sent to the printer on January 9, 1913, and at the close of the year was nearly ready for distribution. The contents are as follows:

Volume I.

Report of the proceedings of the twenty-seventh annual meeting of the American Historical Association. By Waldo G. Leland, secretary.

Report of the proceedings of the eighth annual meeting of the Pacific coast branch. By H. W. Edwards, secretary of the branch.

The archives of the Venetian Republic. By Theodore F. Jones.

Materials for the history of Germany in the sixteenth and seventeenth centuries. By Sidney B. Fay.

The materials for the study of the English cabinet in the eighteenth century. By Edward Raymond Turner.

François de Guise and the taking of Calais. By Paul van Dyke.

Factions in the English privy council under Elizabeth. By Conyers Read.

Anglo-Dutch relations, 1671–1672. By Edwin W. Pahlow.

American-Japanese intercourse prior to the advent of Perry. By Inazo Nitobe.

Colonial society in America. By Bernard Moses.

French diplomacy and American politics, 1794–1795. By James Alton James.

The insurgents of 1811. By D. R. Anderson.

The tariff and the public lands from 1828 to 1833. By Raynor G. Wellington.

The "Bargain of 1844" as the origin of the Wilmot proviso. By Clark E. Persinger.

Monroe and the early Mexican revolutionary agents. By Isaac Joslin Cox.

Public opinion in Texas preceding the Revolution. By Eugene C. Barker.

Relations of America with Spanish America, 1720–1744. By H. W. V. Temperley.

The genesis of the Confederation of Canada. By Cephas D. Allin.

Proceedings of the eighth annual conference of historical societies.

List of European historical societies.

Twelfth report of the public archives commission. By Herman V. Ames, chairman.

    Appendix A. Proceedings of the third annual conference of archivists.

    Appendix B. Report on the archives of the State of Colorado. By James F. Willard.

    Appendix C. List of commissions and instructions to governors and lieutenant governors of American and West Indian Colonies, 1609–1784.

Writings on American history, 1911. By Grace G. Griffin.

Volume II.

Ninth report of the historical manuscripts commission: Correspondence of Alexander Stephens, Howell Cobb, and Robert Toombs.

PUBLICATIONS OF THE SOCIETY OF THE DAUGHTERS OF THE AMERICAN REVOLUTION.

The manuscript of the Fifteenth Annual Report of the National Society of the Daughters of the American Revolution for the year ending October 11, 1912, was communicated to Congress March 19, 1913.

THE SMITHSONIAN ADVISORY COMMITTEE ON PRINTING AND PUBLICATION.

The editor has continued to serve as secretary of the Smithsonian advisory committee on printing and publication. To this committee have been referred the manuscripts proposed for publication by the various branches of the Institution, as well as those offered for printing in the Smithsonian publications. The committee also considered forms of routine, blanks, and various matters pertaining to printing and publication, including the qualities of paper suitable for text and plates. Twenty-two meetings were held and 138 manuscripts were acted upon.

Respectfully submitted.

A. HOWARD CLARK, *Editor.*

Dr. CHARLES D. WALCOTT,
   Secretary of the Smithsonian Institution.

APPENDIX 9.

ADVISORY COMMITTEE ON THE LANGLEY AERO-DYNAMICAL LABORATORY.[1]

OFFICIAL STATUS.

Authorization.—On May 1, 1913, the Regents of the Smithsonian Institution, approving a general scheme submitted by Secretary Walcott, authorized the secretary, with the approval of the executive committee, to reopen the Langley Aerodynamical Laboratory; to appoint an advisory committee; to add, as means are provided, other laboratories and agencies; to group them into a bureau organization; and to secure the cooperation with them of the Government and other agencies.

Functions.—The committee is to advise as to the organization and work of the Langley Aerodynamical Laboratory and of the bureau organization when adopted, and the coordination of their activities with the kindred labors of other establishments, governmental and private; it is to plan for such theoretical and experimental investigations, tests, and reports as may serve to increase the safety and effectiveness of aerial locomotion for the purposes of commerce, national defense, and the welfare of man. But neither the committee nor the Smithsonian Institution will promote patented devices, furnish capital to inventors, or manufacture commercially, or give regular courses of instruction for aeronautical pilots or engineers.

The organization, under regulations to be established and fees to be fixed by the secretary, approved by the Smithsonian executive committee, may exercise its functions for the military and civil departments of the Government of the United States, and also for any individual, firm, association, or corporation within the United States; provided, however, that such department, individual, firm, association, or corporation shall defray the cost of all material used and of all services of persons employed in the exercise of such functions.

With the approval of the Secretary of the Institution, the committee is to collect aeronautical information, such part of the same as may be valuable to the Government, or the public, to be issued in bulletins and other publications.

Membership and Privileges.—The advisory committee is to be composed of the director of the Langley Aerodynamical Laboratory, when appointed, and one member to be designated by the Secretary of War, one by the Secretary of the Navy, one by the Secretary of Agriculture, and one by the Secretary of Commerce, together with such other persons, to be designated by the Secretary of the Smithsonian Institution, as may be acquainted with the needs of aeronautics, the total membership of such committee not to exceed 14.

The members of the advisory committee, as such, are to serve without compensation, but will have refunded the necessary expenses incurred by them in going to Washington to attend the meetings of the committee and returning therefrom, and while attending the meetings.

Approval of the President.—On May 9, 1913, the President of the United States, by request of the Secretary of the Smithsonian Institution, approved the designation of representatives of the above-named departments to serve on the advisory committee.

ORGANIZATION.

Officers.—The advisory committee, as constituted at its organization meeting, convened by Secretary Walcott at the Smithsonian Institution, May 23, 1913, comprises a chairman, a recorder, and 12 additional members, all of whom are to serve for one year. The officers are to be elected annually on or about May 6, and the members for the ensuing year are to be appointed prior to the date of such election.

The chairman has general supervision of the work of the advisory committee, presides at its meetings, receives the reports of the subcommittees, and makes an annual report to the Secretary of the Smithsonian Institution. Said report must include an account of the work done for any department of the Government, individual, firm, association, or corporation, and the amounts paid by them to defray the cost of material and services, as hereinbefore mentioned.

The recorder keeps the minutes of the meetings of the committee and assists the chairman in conducting correspondence and preparing reports pertaining to the business of the committee.

Subcommittees.—The chairman, with the approval of the advisory committee, may appoint standing and special subcommittees to perform such functions as may be assigned to them.

The standing subcommittees may have assigned to them investigations and tests of a permanent character, which they may prosecute from year to year and on which they are to make quarterly reports to the chairman, followed by an annual report. Each subcommittee comprises a chairman, who must be a member of the advisory committee, and others, chosen by him from that committee or elsewhere.

AGENCIES, RESOURCES, AND FACILITIES.

Smithsonian Institution.—The advisory committee has been provided by the Smithsonian Institution with suitable office headquarters, an administrative and accounting system, library and publication facilities, lecture and assembly rooms, and museum space for aeronautic models. The Langley Aerodynamical Laboratory has an income provided for it not to exceed $10,000 the first year (of which $5,000 has been allotted), and $5,000 annually for five years.

United States Bureau of Standards.—For the exact determination of aerophysical constants, the calibration of instruments, the testing of aeronautic engines, propellers, and materials of construction, the committee has the cooperation of the United States Bureau of Standards, from which the Secretary of Commerce has designated one representative.

This bureau has a complete equipment for studying the mechanics of materials and structural forms used in air-craft; for standardizing the physical instruments—thermometers, barographs, pressure gauges, etc.—used in air navigation; and for testing the power, efficiency, etc., of aeronautical motors in a current of air representing the natural conditions of flight.

In these general branches the technical staff of the bureau is prepared to undertake such theoretical and experimental investigations as may come before the advisory committee on behalf of either the Government or private individuals or organizations.

United States Weather Bureau.—For studies of and reports on every phase of aeronautic meteorology, besides the usual forecasting, the committee has the cooperation of the United States Weather Bureau, from which the Secretary of Agriculture has designated one representative.

This bureau has an extensive library of works on or allied to aeronautics, an instrument division for every type of apparatus for studying the state of the atmosphere, a whirling table of 30-foot radius for standardizing anemometers, a complete kite equipment with power reel, and a sounding balloon equipment with electrolytic hydrogen plant, all of which are available for scientific investigations. For special forecasts, anticipating field tests or cross-country voyages, the general service of the bureau may be called upon.

War and Navy Departments.—These departments, while especially interested in aeronautics for national defense, can be of service in advancing the general science. Each has an aeronautical library; each has an official representative in foreign countries who reports periodically on every important phase of the art, whether civil or military; each has an assignment of officers who design, test, and operate air craft, and who determine largely the scope and character

of their development; each has its aeronautic station equipped with machines in actual service throughout the year. Besides various aviation establishments, the War Department has a balloon plant at Fort Myer, Va., and at Omaha, Nebr.; the Navy has its marine model basin, useful for special experiments in aeronautics, its extensive shops at the Washington Navy Yard, available for the alteration or repair of air craft or the manufacture of improved military types, and at Fort Myer three lofty open-work steel towers suitable for studies in meteorology or aerodynamics in the natural wind. Furthermore, the Navy Department has detailed an officer for special research in aeronautics at one of the principal engineering schools.

Because of their fundamental interest in aeronautics, each of these departments has two representatives on the advisory committee, and each will be able to place at the service of the committee one or more skilled aviators and aeroplanes for systematic experimentation.

PRESENT NEEDS.

In presenting the needs of the organization, it is well to remark that the Smithsonian Institution possesses the unique character of being a private organization having governmental functions and prerogatives. It can receive appropriations directly from Congress; it can be the recipient or the custodian of private funds for the increase and diffusion of knowledge; it can deposit such private funds with the United States Treasury, or place them otherwise, as may be required by the donor. Likewise, it can be the recipient or custodian of material objects representing any province of nature or any branch of human knowledge or art. This unique character allows the public to anticipate or supplement the cooperation of Congress in promoting the aerodromical (aeronautical) work of the Institution.

Endowment funds.—Persons approving the purpose of the organization and desiring its continuity and permanence can not do better than to provide for it a steady income, either for general or for specific use. Individual endowment funds bearing the name of the giver or other person, and presented to the Smithsonian Institution, or placed in its custody at the disposal of the committee, may be recommended; also collective funds bearing the name of a society, organization, or section of the country, whether in the interest of scientific progress or of national defense.

Temporary funds.—For the prompt achievement of definite results, funds may well be offered for immediate application, both of principal and interest; as, for example, for the erection of laboratories or other buildings; for the purchase of experimental air craft, or apparatus, instruments, etc.

Most needed is an expansion of the Langley Aerodynamical Laboratory providing a large and a small wind tunnel, ampler shops, and

instrument and model rooms. Adjacent to this, or forming a part of it, may well be the headquarters of the committee, with the collections of aeronautic publications and exhibits, and with designing rooms where plans for air craft may be matured by fabricators in consultation with the technical staff. This new building, if placed on the Smithsonian grounds, should be of good architecture and cost not less than $100,000.

Of immediate importance is an air-craft field laboratory, adjacent to ample flying space of land and water, and adapted to assembling, adjusting, and repairing several full-scale land and water aeroplanes, and subjecting them to indoor tests and measurements, as of stress, strain, factor of safety, center of gravity, moment of inertia, working condition, etc. One such plant suitably located would serve all governmental and civilian requirements for the present. A suitable site is the public land in Potomac Park in the vicinity of the Smithsonian Institution. Here might be held air-craft competitions under the auspices of the Government.

Prizes and awards.—As a stimulus to the highest aeronautic achievement, or as an honorable recognition thereof, suitable prizes or awards might advantageously be offered. Provision should be made for liberal cash prizes for competitive tests of motors, propellers, etc., in a purely scientific way not trenching upon the province of aero clubs.

Fellowships.—For the prosecution of special aeronautic investigations in cooperation with the advisory committee, educational institutions and scientific or engineering organizations should be provided with research fellowships whose incumbents may have the counsel of the committee and the advantage of its equipments.

Until adequate appropriations have been made by the Government the activities of the organization and committee will have to be sustained largely by private resources.

REPORT OF THE EXECUTIVE COMMITTEE OF THE BOARD OF REGENTS OF THE SMITHSONIAN INSTITUTION FOR THE YEAR ENDING JUNE 30, 1913.

To the Board of Regents of the Smithsonian Institution:
Your executive committee respectfully submits the following report in relation to the funds, receipts, and disbursements of the Institution, and a statement of the appropriations by Congress for the National Museum, the International Exchanges, the Bureau of American Ethnology, the National Zoological Park, the Astrophysical Observatory, and the International Catalogue of Scientific Literature for the year ending June 30, 1913, together with balances of previous appropriations:

SMITHSONIAN INSTITUTION.

Condition of the fund July 1, 1913.

The permanent fund of the Institution and the sources from which it has been derived are as follows:

DEPOSITED IN THE TREASURY OF THE UNITED STATES.

Bequest of Smithson, 1846		$515, 169. 00
Residuary legacy of Smithson, 1867		26, 210. 63
Deposit from savings of income, 1867		108, 620. 37
Bequest of James Hamilton, 1875	$1, 000. 00	
Accumulated interest on Hamilton fund, 1895	1, 000. 00	
		2, 000. 00
Bequest of Simeon Habel, 1880		500. 00
Deposits from proceeds of sale of bonds, 1881		51, 500. 00
Gift of Thomas G. Hodgkins, 1891		200, 000. 00
Part of residuary legacy of Thomas G. Hodgkins, 1894		8, 000. 00
Deposit from savings of income, 1903		25, 000. 00
Residuary legacy of Thomas G. Hodgkins, 1907		7, 918. 69
Deposit from savings of income, 1913		636. 94
Bequest of William Jones Rhees, 1913		251. 95
Deposit of proceeds from sale of real estate (gift of Robert Stanton Avery), 1913		9, 692. 42
Total amount of fund in the United States Treasury		955, 500. 00

<div align="center">OTHER RESOURCES.</div>

Registered and guaranteed bonds of the West Shore Railroad Co.,
  part of legacy of Thomas G. Hodgkins (par value) _____ $42,000.00

    Total permanent fund_____ 997,500.00

Also three small pieces of real estate bequeathed by Robert Stanton Avery, of Washington, D. C., one of the original four pieces and part of another having been sold during the year and the proceeds deposited in the United States Treasury as an addition to the permanent fund.

That part of the fund deposited in the Treasury of the United States' bears interest at 6 per cent per annum; under the provisions of the act of Congress of August 10, 1846, organizing the Institution, and the act approved March 12, 1894. The rate of interest on the West Shore Railroad bonds is 4 per cent per annum. The real estate received from Robert Stanton Avery is exempt from taxation and yields only a nominal revenue from rentals.

Statement of receipts and disbursements from July 1, 1912, to June 30, 1913.

<div align="center">RECEIPTS.</div>

Cash on deposit July 1, 1912_____		$33,060.09
Interest on fund deposited in United States Treasury due July 1, 1912, and Jan. 1, 1913_____	$56,695.12	
Interest on West Shore Railroad bonds due July 1, 1912, and Jan. 1, 1913_____	1,680.00	
Repayments, rentals, publications, sale of real estate, etc_	17,920.12	
Contributions from various sources for specific purposes_	16,575.50	
		92,870.74
		125,930.83

<div align="center">DISBURSEMENTS.</div>

Buildings, care and repairs_____		5,715.66
Furniture and fixtures _____		1,396.97
General expenses:		
Salaries _____	$18,804.31	
Meetings _____	339.00	
Stationery_____	810.13	
Postage, telegraph, and telephone_____	710.29	
Freight_____	98.85	
Incidentals _____	2,058.52	
Garage_____	2,448.74	
Fuel and lights_____	91.26	
		25,361.10
Library _____		2,892.50
Publications and their distribution:		
Miscellaneous collections _____	4,936.32	
Reports _____	825.18	
Special publications_____	454.51	
Publication supplies_____	336.27	
Salaries_____	6,558.00	
		13,110.28
Explorations, researches, and collections_____		20,893.43
Hodgkins specific fund, researches and publications_____		1,664.96
International Exchanges _____		4,289.92

Gallery of Art	$29. 63
Advances for field expenses, etc	6, 305. 67
Deposited to credit of permanent fund	10, 581. 31
Langley Aerodynamical Laboratory	48. 00
	92, 289. 43
Balance, June 30, 1913, deposited with the Treasurer of the United States	33, 641. 40
	125, 930. 83

By authority your executive committee again employed Mr. William L. Yaeger, a public accountant of this city, to audit the receipts and disbursements of the Smithsonian Institution during the period covered by this report. The following certificate of examination supports the foregoing statement, and is hereby approved:

WASHINGTON. D. C., *July 31, 1913.*

EXECUTIVE COMMITTEE BOARD OF REGENTS,
Smithsonian Institution.

SIRS : I have examined the accounts and vouchers of the Smithsonian Institution for the fiscal year ending June 30, 1913. and certify the following to be a correct statement:

Total receipts	$92, 870. 74
Total disbursements	92, 289. 43
Excess of receipts over disbursements	581. 31
Amount from July 1. 1912	33, 060. 09
Balance on hand June 30. 1913	33, 641. 40
Balance shown by Treasury statement June 30, 1913	39, 342. 24
Less outstanding checks	5, 700. 84
True balance June 30, 1913	33, 641. 40

The vouchers representing payments from the Smithsonian income during the year, each of which bears the approval of the secretary, or. in his absence. of the acting secretary, and a certificate that the materials and services charged were applied to the purposes of the Institution, have been examined in connection with the books of the Institution and agree with them. excepting voucher No. 3514. to Andrew D. White for $50, which was canceled together with check after entry upon the books. for which credit will be given in July account.

(Signed)   WILLIAM L. YAEGER,
Public Accountant and Auditor.

All moneys received by the Smithsonian Institution from interest, sales, refunding of moneys temporarily advanced, or otherwise, are deposited with the Treasurer of the United States to the credit of the Institution, and all payments are made by checks signed by the secretary.

The expenditures made by the disbursing agent of the Institution and audited by the Auditor for the State and Other Departments are reported in detail to Congress and will be found in the printed document.

Your committee also presents the following summary of appropriations for the fiscal year 1913 intrusted by Congress to the care of the Smithsonian Institution, balances of previous appropriations at the beginning of the fiscal year, and amounts unexpended on June 30, 1913:

	Available after July 1, 1912.	Balance June 30, 1913.
Appropriations committed by Congress to the care of the institution:		
[....]	$5.02	[1] $5.02
[....]	2,973.13	.31
[....]	32,000.00	4,065.41
[....]	580.64	[1] 365.51
[....]	2,576.64	50.56
[....]	42,000.00	4,288.61
[....]	213.83	[1] 209.45
[....]	3,802.73	612.59
Astrophysical Observatory, 1913	13,000.00	516.38
[....]	4.50	[1] 4.50
[....]	682.04	25.95
[....]	7,500.00	681.58
[....]	946.06	[1] 946.06
[....]	287.04	[1] 287.04
[....]	37,359.32	1.54
[....]	50,000.00	11,617.95
[....]	4,153.20	[1] 4,153.20
[....]	4,036.43	124.68
[....]	50,000.00	12,689.65
[....]	7,030.94	[1] 1,132.28
[....]	8,932.37	1,355.71
[....]	300,000.00	17,393.54
Books, 1911	42.76	[1] 14.97
Books, 1912	690.30	26.54
Books, 1913	2,000.00	845.21
Postage, 1913	500.00	....
Building repairs, 1911	108.19	[1] 108.19
[....]	4,751.95	18.44
[....]	10,000.00	576.05
[....]	1,675.65	1,613.25
[....]	10.74	[1] 40.74
[....]	4,970.35	186.83
Bric[....]	100,000.00	9,459.75
	20,000.00	18,224.02

[1] Carried to credit of surplus fund.

Statement of estimated income from the Smithsonian fund and from other sources, accrued and prospective, available during the fiscal year ending June 30, 1914.

Balance June 30, 1913 _____ $33,641.40

Interest on fund deposited in United States Treasury,
    due July 1, 1913, and Jan. 1, 1914 _____ $57,726.33

Interest on West Shore Railroad bonds, due July 1, 1913,
    and Jan. 1, 1914 _____ 1,680.00

Exchange repayments, sale of publications, refund of
    advances, etc _____ 7,800.00

Deposits for specific purposes _____ 12,000.00

                                                                                           79,206.33

      Total available for year ending June 30, 1914 _____ 112,847.73

Respectfully submitted.

                                  A. O. BACON,
                                  ALEXANDER GRAHAM BELL,
                                  JOHN DALZELL,

                                         Executive Committee.

WASHINGTON, D. C., *November 22, 1913.*

PROCEEDINGS OF THE BOARD OF REGENTS OF THE SMITH- SONIAN INSTITUTION FOR THE FISCAL YEAR ENDING JUNE 30, 1913.

ANNUAL MEETING DECEMBER 12, 1912.

Present: The Hon. Edward D. White, Chief Justice of the United States, chancellor, in the chair; Senator S. M. Cullom; Senator Henry Cabot Lodge; Senator A. O. Bacon; Representative John Dalzell; Representative Scott Ferris; Representative Irvin S. Pepper; Dr. Andrew D. White; Dr. Aléxander Graham Bell; Mr. Charles F. Choate, jr.; Mr. John B. Henderson, jr.; the Hon. Charles W. Fairbanks; and the secretary, Mr. Charles D. Walcott.

SELECTION OF TEMPORARY CHAIRMAN.

The secretary, in the absence of a presiding officer, called the meeting to order.

On motion, the Chief Justice was invited to the chair.

ANNOUNCEMENT OF DEATH OF CHANCELLOR.

The secretary announced the death of Vice President Sherman, chancellor of the Institution.

Senator Lodge submitted the following resolutions, which were unanimously adopted:

Whereas the Board of Regents of the Smithsonian Institution have received the sad intelligence of the death on October 30, 1912, of James Schoolcraft Sherman, Vice President of the United States and chancellor of the Institution: Therefore be it

Resolved, That in the passing away of this distinguished official the country has lost a man whose unsullied public career and blameless private life marked him as one of the best exemplars of the highest type of American patriotism and citizenship; while this Institution has been deprived of the association of a regent and presiding officer whose loyalty to its purposes and zeal in its interests have been an inspiration to his colleagues;

Resolved, That we tender to the family of Mr. Sherman our respectful and sincere sympathy in their great bereavement;

Resolved, That an engrossed copy of these resolutions be transmitted to the family of the late chancellor.

ELECTION OF CHANCELLOR.

On motion, it was

Resolved, That the Chief Justice of the United States be elected chancellor of the Smithsonian Institution.

APPOINTMENT OF REGENTS.

The secretary announced the appointment, by joint resolution of Congress, approved by the President, of Dr. Andrew D. White, to serve until June 26, 1918, and of the Hon. Charles W. Fairbanks, to serve until July 3, 1918.

RESOLUTION RELATIVE TO INCOME AND EXPENDITURE.

Senator Bacon, chairman of .the executive committee, presented the following resolution, which was adopted:

Resolved, That the income of the Institution for the fiscal year ending June 30, 1914, be appropriated for the service of the Institution, to be expended by the secretary, with the advice of the executive committee, with full discretion on the part of the secretary as to items.

ANNUAL REPORT OF EXECUTIVE COMMITTEE.

Senator Bacon, chairman, submitted the report of the executive committee for the fiscal year ending June 30, 1912.

On motion, the report was adopted.

ANNUAL REPORT OF PERMANENT COMMITTEE.

The secretary, on behalf of the committee, presented the following report for the fiscal year ending June 30, 1912:

Research Corporation.—The development of the Research Corporation, which is handling the Cottrell patents offered to the Institution for the benefit of research, has been progressing steadily during the past year.

The corporation was organized under the laws of the State of New York on February 26, 1912, in essential accordance with the plans explained at the last meeting of the board, on February 8, 1912.

At present a number of installations are being made for the precipitation process that in the near future will bring in a revenue to the corporation.

The work of the corporation has grown so rapidly that it has been found necessary to increase the technical staff and office accommodations in New York.

It must be understood that in the development of any business of this character several years are required for experimentation and the installation of machinery for getting it on a successful working basis.

The George W. Poore bequest.—Three independent appraisals have been made of the valuation of the real estate embraced in the Poore bequest, and a recent offer for the purchase of a few of the lots has been recommended for acceptance by the permanent committee.

A recent report from the executor shows that the estate is being settled as rapidly as possible.

Avery bequest.—Since the last meeting an offer of $5,335 net has been received for an unimproved lot on East Capitol Street, and has been accepted.

On motion, the report was adopted.

ANNUAL REPORT OF THE SECRETARY.

The secretary presented his annual report on the operations of the Institution for the fiscal year ending June 30, 1912.

He stated, in relation to the publications issued by the Institution, that since the last annual meeting of the Regents there had been printed by the Institution and its branches a total of 161 publications, aggregating about 7,000 pages of text and 650 plates of illustrations. Of this aggregate 90 volumes and pamphlets (2,369 pages and 193 plates) pertained to the Institution proper; 68 volumes and pamphlets (3,500 pages and 397 plates) related directly to the work of the National Museum; and 3 volumes (1,041 pages and 68 plates) were descriptive of investigations by the Bureau of American Ethnology. The total number of copies of all publications distributed during the year was about 180,000.

On motion, the report was accepted.

REPORT OF THE COMMITTEE ON THE LANGLEY MEMORIAL TABLET.

Senator Lodge, chairman of the committee, submitted the following report:

" Your committee on the Langley memorial tablet begs to report that Mr. John Flanagan's design, which was accepted by the board at the annual meeting on December 14, 1911, has been cast in bronze, and is now in the place selected for it, the north vestibule of the Smithsonian building."

In this connection the secretary read the following letter:

DECEMBER 10, 1912.

Hon. CHARLES D. WALCOTT,
    Secretary Smithsonian Institution.

DEAR Dr. WALCOTT : I have the pleasure of informing you that the Aero Club of Washington expects to celebrate Langley Day on Tuesday, May 6, 1913, by holding an aviation meet on the Potomac River front, probably at the Washington Barracks, and will be pleased to have the Smithsonian Institution participate in that event and any functions which may be associated with it.

The Army and Navy aviators and various wealthy aero clubmen at large, who own and operate land and water aeroplanes, have expressed their wish to fly on that occasion.

Invitations to the meet will be sent to the officers (and their wives) of the Aero Club of America and to the presidents of the 20 or more affiliated clubs, in addition to the usual Washington list, comprising representatives of the official and social life of the city.

If the Smithsonian Institution contemplate any ceremony for that date or thereabout, the board of management of the Aero Club will be pleased to accommodate its plans to any you may have in view for that time.

Very truly, yours,

A. F. ZAHM,
Secretary Aero Club of Washington.

The secretary said that in view of the facts set forth in Dr. Zahm's letter it had occurred to him that the Langley Day celebration would be a very appropriate time for the unveiling of this tablet.

On motion, the report of the committee was accepted with thanks, and the committee requested to arrange for the unveiling of the tablet on Langley Day.

THE LANGLEY MEDAL.

The secretary stated that at the annual meeting on December 15, 1908, the board had established the Langley medal, the first of which had been awarded to the Wright brothers on February 10, 1910. The committee was now considering another award, and would be ready to report its recommendations at the meeting of the board in February next.

THE SECRETARY'S STATEMENT.

National Museum.—The work of installation in the exhibition halls of the new building has been pushed with so much vigor since the beginning of the year that in the course of another month the last of these halls, being those devoted to the mammals and to prehistoric archeology, should be ready for the public.

Evans collection.—It is extremely gratifying to note the continued and very material interest of Mr. William T. Evans, of New York, in the welfare of the National Gallery of Art. Beginning in 1907 with a tender of 50 paintings by contemporary American artists, and twice increasing the extent of his offer, first to 100 paintings and later to 100 artists, Mr. Evans has recently completed this important gift, which comprises a total of 139 paintings. The collection is not only the most prominent feature of the gallery now installed in Washington but is also a remarkable presentation of modern American art.

Senator Lodge submitted the following resolution, which was adopted:

Resolved, by the Board of Regents of the Smithsonian Institution, That the secretary be directed to convey to Mr William T. Evans the expression of their sense of deep obligation for his continued and valuable donations to the National Gallery of Art, constituting a collection representative to a remarkable degree of the work and talent of contemporary American painters.

SMITHSONIAN EXPEDITIONS.

A brief résumé of the results obtained follows:

Biological survey of the Panama Canal Zone.—This survey was completed and the work accomplished was very valuable to science. It included collections and observations of vertebrate animals, land and fresh-water mollusks, and flowering plants (including grasses) and ferns. Collections had been made of fishes, reptiles, and amphibians, birds and mammals, and special studies and collections had been made of the microscopic plant and animal life of the fresh waters of the zone. Pamphlets had been issued from time to time describing new forms of animals and plants, and as soon as the mass of material could be worked up a more general account of the results of the survey would be accomplished.

Rainey African expedition.—The Paul J. Rainey expedition referred to at the last meeting came to a successful close during the winter of 1911–12. Mr. Edmund Heller, a Smithsonian naturalist and a member of the Smithsonian African expedition, accompanied Mr. Rainey and reported collections as follows:

Mammals (large)	750
Mammals (small)	5,000
Birds	400
Reptiles	2,000
Miscellaneous	500
	8,650

During the entire expedition Mr. Heller was Mr. Rainey's guest. Mr. Rainey gave him all the native assistants that he could use and accorded him perfect freedom as regards choice of collecting ground. Mr. Heller was thus able to visit the exact regions from which material was most needed to supplement that procured by the Smithsonian African expedition. After studying the mammals in the British Museum Mr. Heller reported that the United States National Museum now had the finest series of East African mammals in the world.

Eighty lions were secured on the expedition. which more than tripled the highest previous record for Africa.

The Childs-Frick African expedition.—This expedition left New York in October, 1911, and arrived at Djibouti, on the Red Sea, in French Somaliland. November 22. As previously stated, it was accompanied by Col. Edgar A. Mearns. United States Army, retired, who was a member of the Smithsonian African expedition.

The Frick party traversed the territory lying north of that visited by Col. Roosevelt and Mr. Rainey. covering at the same time certain parts of Abyssinia. northern British East Africa, and the country

lying about Lake Rudolf. The expedition ended about September 1, 1912, and the party sailed for America on September 16.

The collections as a whole embraced plants, mammals, birds, reptiles, bactrachians, fishes, mollusks, crustaceans, and other invertebrates. About 5,000 birds were obtained for the National Museum.

Borneo expedition.—The board would recall that Dr. W. L. Abbott, a collaborator of the United States National Museum, very generously contributed the sum of $5,000 for carrying on an expedition to Dutch East Borneo. Reports had been received that the expedition was successful, but as yet the specimens acquired had not been shipped.

Lyman Siberian expedition.—The expedition to the Altai Mountains, in Siberia, which was financed by Dr. Theodore Lyman, of Cambridge, Mass., left Washington May 21, 1912, and returned September 16, 1912. As arranged, Mr. Ned Hollister, a naturalist in the National Museum, accompanied Dr. Lyman. The expedition resulted in the securing of 350 mammals, 300 birds, and 100 miscellaneous specimens.

The mammals would remain in the National Museum, while the birds were intended for the Museum of Comparative Zoology, Cambridge. The scientific work was entirely in charge of Mr. Hollister, assisted by an experienced alpinist, Conrad Kain. The region covered lay in the Kurai district, Government of Tomsk. The collection of mammals was one of the most important received in recent years, as the region was hitherto unrepresented in the Museum, and the fauna was of special interest on account of its close relationship with that of the United States.

British Columbia expedition.—Under the direction of the secretary an expedition was undertaken in British Columbia north of the Yellowhead Pass route of the new Grand Trunk Pacific Railway.

Outfitting at Fitzhugh, the party entered the high mountain ranges northwest of the Yellowhead Pass, 275 miles north of the forty-ninth parallel—the boundary between the United States and Canada. Two of the young men of the party collected mammals, the skins and skulls of which are now in the National Museum.

The special work of the secretary was to determine upon the best locality for a geological section of the mountain ranges forming the main mass of the Canadian Rockies in this region. A general section was carried across the main range in such a manner as to ascertain that there was a thickness of some 12,000 feet of Cambrian fossiliferous sedimentary rocks and 3,000 feet of Ordovician strata above. In other words, the main mountain peaks and ridges of this region, one of the most picturesque known in America, were carved by the action of rain, frost, snow, and ice from this great series of sandstones and limestones.

Large collections were also made from the famous Burgess Pass fossil locality.

Algerian expedition.—In 1911 the attention of the board was called to the work of Director Abbot, of the Astrophysical Observatory, in connection with studies of the sun as a variable star. He was sent to Bassour, Algeria, to observe the so-called "solar constant of radiation," while similar observations were made at the Mount Wilson (Cal.) station by Assistant L. B. Aldrich. These measurements had been reduced and strongly confirm the supposed variability of the sun.

In May, 1912, Mr. Abbot returned to Algeria, while Aid F. E. Fowle made observations in California. The results were not yet reduced, but little doubt was felt that they would be quite sufficient to fully prove the supposed variability of the sun.

A most interesting observation was made by Messrs. Abbot and Fowle in connection with this work. It will be recalled that on June 6, 1912, a volcanic eruption took place in Alaska. Mr. Abbot noted on June 19 (only 13 days after the eruption) a smoky appearance in the sky, which rapidly increased. Throughout the remainder of his stay in Algeria the sky assumed a whitish hazy appearance and the quantity of the direct radiation from the sun was reduced about 25 per cent below that he had observed in the preceding year. Similarly, Mr. Fowle observed the same appearances beginning with June 21, but owing to the greater elevation of his station on Mount Wilson the decrease in the intensity of the direct solar radiation was not quite so great as had been found in Algeria. Similar effects were noted in Washington, beginning June 11, and have lasted ever since.

Mr. Abbot made in Algeria some measurements of the radiation diffused from the sky, and he drew the conclusion that the total radiation of the sky and the sun combined was less during the summer of 1912 by about 7 or 8 per cent than generally during the same months. This defect in the quantity of the radiation available to warm the earth would naturally have produced a decrease in the earth's temperature. Hence the pronounced coolness of the past summer seems to be explained as due to the world-wide dissemination of a blanket of volcanic dust from the Alaska eruption.

Lake Baikal region, Siberia.—Mr. George Mixter, of Boston, Mass., an experienced big-game hunter, volunteered to get material for the Museum at and near Lake Baikal during the summer of 1912 and was appointed a collaborator for two years. He reports the capture of two bear, several Baikal seal, various small mammals, and a collection of fish from the lake, but no specimens have been received. He has not yet returned.

British North Borneo.—Mr. D. D. Streeter, jr., of Brooklyn, N. Y., volunteered to collect in British North Borneo for the Museum and was appointed collaborator for two years. He left New York about April 15, 1912, and has sent a few reptiles and bats taken in Algeria on his way eastward.

Alaskan boundary.—Mr. Copley Amory, jr., of Cambridge, Mass., volunteered to accompany the Coast and Geodetic Survey party engaged in surveying the Alaskan-Canadian boundary. He was appointed collaborator of the National Museum and joined the party in the field about July 10, 1912, remaining throughout the season. He reports excellent results, including the capture of six or more caribou, probably of a species hitherto known from a few skulls only, but no specimens have yet been received.

North China.—Mr. A. de C. Sowerby is making collections in North China for the National Museum through the liberality of a gentleman who desires that his identity be not disclosed. Mr. Sowerby's work has been interrupted by the Chinese revolution, but he has recently sent in six wild sheep, two Manchurian wapiti, and a few other mammals, birds, and reptiles collected in northern Shansi in May, 1912.

Siberia and Mongolia.—I would ask the board's attention to the anthropological researches conducted in Siberia and Mongolia by Dr. Aleš Hrdlička, Curator, division of physical anthropology, United States National Museum, as mentioned on page 11 of the annual report. Dr. Hrdlička is now preparing for an expedition to South America, where he will work in conjunction with the Panama-California Exposition of San Diego. His specimens will ultimately find their way to the National Museum.

REGULAR MEETING, FEBRUARY 13, 1913.

Present: The Hon. Edward D. White, Chief Justice of the United States, chancellor, in the chair: Senator Henry Cabot Lodge; Senator A. O. Bacon; Representative John Dalzell; Dr. Alexander Graham Bell; the Hon. George Gray; Mr. Charles F. Choate, jr.; Mr. John B. Henderson, jr.; and the secretary, Mr. Charles D. Walcott.

REAPPOINTMENT OF REGENT.

The secretary announced the reappointment of Judge Gray as a citizen Regent, by joint resolution of Congress, approved by the President, to serve until February 7, 1919.

USE OF THE AUDITORIUM IN THE NEW BUILDING OF THE UNITED STATES NATIONAL MUSEUM.

After discussion the following regulations were adopted:

1. The use of the auditorium is authorized for any meetings or other functions originating with the Institution.

2. The secretary of the Institution is authorized, in his discretion, to grant the use of the auditorium—

(a) To organizations having objects and activities directly related to those of the Institution, and

(b) For Government purposes upon the request of the President, the Secretary of an Executive Department, or the head of an independent branch.

3. All requests for the use of the auditorium for purposes other than as above indicated shall be submitted to the permanent committee, who are empowered to act.

4. All extra expenses attendant upon the use of the auditorium, except by the Institution and its branches, shall be paid by the organization or Government branch having such use

DONATION OF JOHN B. HENDERSON, JR.

The secretary stated that Mr. Henderson had donated the sum of $500 for the construction at the Zoological Park of an outside cage for the parrots, in which these birds were now thriving satisfactorily.

Mr. Choate offered the following resolution, which was adopted:

Resolved, That the thanks of the Board of Regents of the Smithsonian Institution are hereby tendered to their colleague, Mr. John B. Henderson, jr., for his generosity in providing the funds requisite for the construction of an open-air cage for certain birds at the National Zoological Park.

GIFT OF MRS. EDWARD H. HARRIMAN.

The secretary announced the gift to the Institution by Mrs. Edward H. Harriman of a set of the publication, The North American Indian, by Edward S. Curtis, a project involving 20 volumes and an expenditure from first to last of nearly $1,000.000.

Eight volumes and portfolios had been issued and delivered to the Institution, and the remaining 12 would be received as printed.

Judge Gray offered the following resolution, which was adopted:

Resolved, That the thanks of the Board of Regents of the Smithsonian Institution be tendered to Mrs. Edward H. Harriman for the gift of a set of The North American Indian, by Edward S. Curtis, and especially for the kindly feeling that prompted her in bestowing this valuable work upon the Institution.

SMITHSONIAN AFRICAN EXPEDITION.

The secretary spoke as follows:

" Considerable interest is being taken by the public in relation to the disposition of the collections made by the Smithsonian African expedition under the leadership of Col. Theodore Roosevelt, also as

to the people who contributed the money for paying the proportionate share of the expenses of the three men sent out by the Smithsonian with Col. Roosevelt.

"The collections, when received, were distributed to the various departments of the National Museum to which they pertained; the birds were sent to the bird department, the large animals to the mammal department, the plants to the botanical department, and so on. A number of groups of the large mammals have been prepared, and a number of individual specimens mounted for exhibition purposes. The greater portion of the specimens have been placed in the study series, and the duplicates will be distributed by exchange or otherwise.

"The groups of large mammals now mounted will shortly be placed on exhibition in the new museum mammal hall where the larger animals will be exhibited. Those that were on exhibition have been temporarily withdrawn, in order to assign them to their proper place in the classification in the hall, which is closed temporarily pending the arrangement of the cases containing the specimens.

"It now seems an opportune time to make a final statement relating to the expedition, and with this in view the secretary recently communicated with the parties who contributed to the fund, and has thus far received replies from the following that they have no objection to their names being given to the public. In this connection the secretary wishes to state that up to this week Col. Roosevelt has not known who the contributers were, with the exception of Mr. Carnegie and possibly one or two personal friends.

"It has not been the custom of the Institution to publish the names of contributors to research work or expeditions conducted under its direction until such enterprise had been completed, and only then when the contributor had no objection to such publication.

"The contributors include Mr. Edward D. Adams, of New York City; Hon. Robert Bacon, of Boston, Mass.; Mr. Cornelius N. Bliss, of New York City; Mr. James Campbell, of St. Louis, Mo.; Mr. W. Bayard Cutting, of New York City; Mr. Andrew Carnegie, of New York City: Mr. Cleveland H. Dodge, of New York City; Mr. E. H. Gary, of New York City; Mr. John Hays Hammond, of Washington, D. C.; Col. H. L. Higginson, of Boston, Mass.; Mr. Hennen Jennings, of Washington, D. C.; Mr. J. S. Kennedy, of New York City; Mr. Ralph King, of Cleveland, Ohio: Hon. George von L. Meyer, of Washington, D. C.; Mr. D. O. Mills, of New York City; Hon. T. H. Newberry, of Michigan; Mr. L. L. Nunn, of Provo, Utah; Mr. H. C. Perkins, of Washington, D. C.; Mr. George W. Perkins, of New York City; Mr. Henry Phipps, of New York City; Mrs. Whitelaw Reid, of New York City: Hon. Elihu Root, of Washington,

D. C.; Mr. J. C. Rosengarten, of Philadelphia, Pa.; Mr. Jacob H. Schiff, of New York City; Mr. Isaac N. Seligman, of New York City; Mr. O. M. Stafford, of Cleveland, Ohio; Hon. Oscar S. Straus, of New York City; and Mr. Isidor Straus, of New York City.

"From the contributions the Smithsonian's three-fifths' share of all the expenses were paid; the other two-fifths were paid by Col. Roosevelt, which covered all his personal expenses and those of his son and their proportionate two-fifths' share of the total expenses of the expedition.

"The following is the complete list of the collection made by the expedition that have been received by the Institution:

Mammals	5,013
Birds	4,453
Birds' eggs and nests	131
Reptiles and batrachians	2,322
Fish	447
Plants	5,153
Insects	3,500
Shells	1,500
Miscellaneous invertebrates	650
Total specimens	23,169

"As the result of this expedition the biological collections now in the National Museum from East Africa are probably the most complete and systematic of any in the world."

AWARD OF LANGLEY MEDALS.

The committee on the Langley medal presented the following report:

WASHINGTON, D. C., *February 13, 1913.*

Hon. CHARLES D. WALCOTT,
    Secretary Smithsonian Institution.

DEAR SIR: The committee on the award of the Langley medal recommends that medals be awarded to—

1. Monsieur Gustave Eiffel, for advancing the science of aerodromics by his researches relating to the resistance of the air in connection with aviation.

2. Mr. Glenn H. Curtiss, for advancing the art of aerodromics by his successful development of a hydroaerodrome, whereby the safety of the aviator has been greatly enhanced.

Respectfully submitted.

ALEXANDER GRAHAM BELL.
JAMES MEANS.
J. A. BRASHEAR.

After remarks by Dr. Bell, the following resolution was adopted:

Resolved, That the Board of Regents of the Smithsonian Institution approve the recommendations of the committee on the Langley medal that said medal be awarded to Gustave Eiffel and Glenn H. Curtiss for advances in the science and art of aerodromics, respectively; and that arrangements be made to present the medals on May 6, 1913 (Langley day).

AERODYNAMICAL LABORATORY.

The secretary brought before the board the question of the establishment of a laboratory for the study of aerodynamics under the direction of the Institution. He spoke of the work done by the late Secretary Langley under the auspices of the Smithsonian Institution and the War Department, and of the studies being conducted by other nations which had regularly established laboratories.

After full discussion of the question, the following resolution was adopted:

Resolved, That the subject matter of the secretary's recommendations be referred to a committee of three. to be appointed by the chancellor, to report at the next meeting of the board.

The chancellor appointed as the committee Judge Gray, Dr. Bell, and Mr. Dalzell.

AMERICAN SCHOOL OF ARCHEOLOGY AT PEKIN.

The secretary said:

" The American School of Archeology in China was launched at a meeting held at the Smithsonian Institution at 10 a. m., January 3, 1913, by a committee consisting of Dr. Harry L. Wilson, president of the Archeological Institute of America; Dr. Charles D. Walcott, secretary of the Smithsonian Institution: and Mr. Charles L. Freer, of Detroit.

" According to a statement submitted by Prof. Francis W. Kelsey, of the University of Michigan, who appeared before. the committee by invitation, the objects of the school are: First, to prosecute archeological research in Eastern China; second, to afford opportunity and facilities for investigation to promising and exceptional students, both foreign and native, in Asiatic archeology; third, to preserve objects of archeological and cultural interest in museums in the countries to which they pertain, in cooperation with existing organizations, such as the China Monuments Society, the Société d'Ankor, etc.

" The management of the affairs of the school was placed in the hands of an executive committee of five. consisting of Dr. Charles D. Walcott, of the Smithsonian Institution; Mr. Charles Henry Butler, reporter of the Supreme Court: Dr. Harry L. Wilson, of Johns Hopkins University; Mr. Charles L. Freer, of Detroit; and Mr. Eugene Meyer, jr., the New York financier.

" Besides the above mentioned executive committee there were also present by invitation Prof. Francis W. Kelsey, Prof. Mitchell Carroll, Mr. Frederick McCormick, and Mr. William H. Holmes.

" The purposes and great possibilities of this movement for first turning American archeological research directly to eastern Asia

has already, since the proposal was made in October last, excited great interest in American scientific and educational circles.

"The general committee consists of: Former President James B. Angell, of the University of Michigan, Ann Arbor; former President Charles W. Eliot, of Harvard University; William Rutherford Mead, the New York architect; Mitchell Carroll, of Washington, D. C.; Charles L. Hutchinson, of Chicago, Ill.; J. Pierpont Morgan, of New York City; Charles Henry Butler, of Washington, D. C.; Mr. Frederick McCormick, of Pekin, who organized in China the first movement for the investigation and protection of Chinese monuments; Henry White, of Washington, D. C.; Francis W. Kelsey, of the University of Michigan; Eugene Meyer, jr., of New York City; Willard D. Straight, secretary of the American group of banks in China; Secretary Charles D. Walcott, of the Smithsonian Institution; Harry L. Wilson, of Johns Hopkins University; Charles L. Freer, of Detroit, Mich.

"Dr. Walcott was elected chairman of the general committee and Mr. Butler its secretary.

"To carry out the program looking to the formation of the American School of Archeology on the soil of China the Hon. Edward T. Williams, first secretary and chargé d'affaires of the American legation in Pekin; Dr. Charles D. Tenney, American consul at Nanking; and the American minister to China, ex officio, were selected to head the advisory committee in China.

"Several American archeologists appeared before the committee during its discussions, including Mr. Edgar L. Hewett, Mr. Charles T. Currelly, and Mr. Langdon Warner.

"Langdon Warner was selected to make a preliminary survey in the Chinese Republic, to cover a period of a year or a year and a half, and to report at the next annual meeting of the general committee on the advisability of establishing the American School of Archeology in China."

SPECIAL MEETING, THURSDAY. MAY 1. 1913.

Present: The Hon. Edward D. White, Chief Justice of the United States, chancellor. in the chair; the Hon. Thomas R. Marshall, Vice President of the United States; Senator Henry Cabot Lodge; Senator A. O. Bacon; Dr. Alexander Graham Bell; the Hon. George Gray; Mr. John B. Henderson, jr.; and the secretary, Mr. Charles D. Walcott.

APPOINTMENT OF REGENTS.

The secretary announced the appointment, by the Vice President, of Senator A. O. Bacon and Senator William J. Stone as Regents of the Institution.

CHAIRMAN OF EXECUTIVE COMMITTEE.

Senator Bacon was reelected chairman of the executive committee.

ACKNOWLEDGMENT OF AWARDS OF THE LANGLEY MEDAL.

BEAULIEUSMER, *February 17, 1913.*

CHARLES WALCOTT,
Secretary of the Smithsonian Institution:

I am very sensible of the great honor that you announce to me, and thank you, begging you to transmit an expression of my appreciation to the council.

GUSTAVE EIFFEL.

CURTISS AVIATION CAMP, NORTH ISLAND,
San Diego, Cal.. February 24, 1913.

Mr. C. D. WALCOTT,
Secretary Smithsonian Institution.

DEAR SIR: I am just in receipt of a communication from the office advising me of the recent award of the Langley medal.

This award is indeed a surprise to me and I greatly appreciate being the recipient.

I will plan to be in Washington on May 6.

Yours, sincerely,   G. H. CURTISS.

BORNEO EXPEDITION.

Announcement was made at the board meeting of February 8, 1912, that Dr. William L. Abbott. a collaborator of the Institution and Museum for many years. had given the Institution $5,000 for use in continuing certain collections in Borneo.

Dr. Abbott has recently sent a check for an additional $3,000 for the work.

THE LANGLEY AERODYNAMICAL LABORATORY.

The committee on the Langley aerodynamical laboratory appointed by the Board of Regents at the meeting of February 13, submitted its report, and after full discussion the following resolutions were adopted:

Whereas the Smithsonian Institution possesses a laboratory for the study of questions relating to aerodynamics, which has been closed since the death of its director, the late Dr. S. P. Langley, formerly Secretary of the Smithsonian Institution; and

Whereas it is desirable to foster and continue, in the institution with which he was connected. the aerodynamical researches which he inaugurated:

Resolved, That the Board of Regents of the Smithsonian Institution hereby authorizes the Secretary of the Institution, with the advice and approval of the executive committee. to reopen the Smithsonian Institution laboratory for the study of aerodynamics, and take such steps as in his judgment may be necessary to provide for the organization and administration of the laboratory on a permanent basis;

That the aerodynamic laboratory of the Institution shall be known as the Langley Aerodynamical Laboratory;

That the functions of the laboratory shall be the study of the problems of aerodromics, particularly those of aerodynamics, with such research and experimentation as may be necessary to increase the safety and effectiveness of aerial locomotion for the purposes of commerce, national defense, and the welfare of man;

That the secretary is authorized to secure, as far as practicable, the cooperation of governmental and other agencies in the development of aerodromical research under the direction of the Smithsonian Institution.

DEATH OF FORMER REGENT JOHN B. HENDERSON.

Judge Gray submitted the following resolution, which was adopted:

Whereas the Board of Regents of the Smithsonian Institution have heard with profound sensibility of the death of the honorable John B. Henderson, long time a member of the board:

Resolved, That a committee of three be appointed by the chancellor to prepare a suitable minute commemorative of his character as a citizen and public servant and of his valuable service to this Institution, to be reported at the next meeting of the board.

The chancellor appointed as the committee Judge Gray, Senator Lodge, and the secretary.

GENERAL APPENDIX

TO THE

SMITHSONIAN REPORT FOR 1913

ADVERTISEMENT.

The object of the GENERAL APPENDIX to the Annual Report of the Smithsonian Institution is to furnish brief accounts of scientific discovery in particular directions; reports of investigations made by collaborators of the institution; and memoirs of a general character or on special topics that are of interest or value to the numerous correspondents of the institution.

It has been a prominent object of the Board of Regents of the Smithsonian Institution, from a very early date, to enrich the annual report required of them by law with memoirs illustrating the more remarkable and important developments in physical and biological discovery, as well as showing the general character of the operations of the institution; and this purpose has, during the greater part of its history, been carried out largely by the publication of such papers as would possess an interest to all attracted by scientific progress.

In 1880 the secretary, induced in part by the discontinuance of an annual summary of progress which for 30 years previous had been issued by well-known private publishing firms, had prepared by competent collaborators a series of abstracts, showing concisely the prominent features of recent scientific progress in astronomy, geology, meteorology, physics, chemistry, mineralogy, botany, zoology, and anthropology. This latter plan was continued, though not altogether satisfactorily, down to and including the year 1888.

In the report for 1889 a return was made to the earlier method of presenting a miscellaneous selection of papers (some of them original) embracing a considerable range of scientific investigation and discussion. This method has been continued in the present report for 1913.

THE EARTH AND SUN AS MAGNETS.[1]

By Dr. GEORGE ELLERY HALE,[2]
Mount Wilson Solar Observatory.

[With 8 plates.]

In 1891 Prof. Arthur Schuster, speaking before the Royal Institution, asked a question which has been widely debated in recent years: " Is every large rotating body a magnet?" Since the days of Gilbert, who first recognized that the earth is a great magnet, many theories have been advanced to account for its magnetic properties. Biot, in 1805, ascribed them to a relatively short magnet near its center. Gauss, after an extended mathematical investigation, substituted a large number of small magnets, distributed in an irregular manner, for the single magnet of Biot. Grover suggested that terrestrial magnetism may be caused by electric currents, circulating around the earth and generated by the solar radiation. Soon after Rowland's demonstration in 1876, that a rotating electrically charged body produces a magnetic field, Ayrton and Perry attempted to apply this principle to the case of the earth. Rowland at once pointed out a mistake in their calculation, and showed that the high potential electric charge demanded by their theory could not possibly exist on the earth's surface. It remained for Schuster to suggest that a body made up of molecules which are neutral in the ordinary electrical or magnetic sense may nevertheless develop magnetic properties when rotated.

We shall soon have occasion to examine the two hypotheses advanced in support of this view. While both are promising, it can not be said that either has been sufficiently developed to explain completely the principal phenomena of terrestrial magnetism. If we turn to experiment, we find that iron globes spun at great velocity in the laboratory fail to exhibit magnetic properties. But this can be accounted for on either hypothesis. What we need is a globe of great size, which has been rotating for centuries at high velocity. The sun, with a diameter 100 times that of the earth (fig. 1), may

throw some light on the problem. Its high temperature wholly pre-cludes the existence of permanent magnets, hence any magnetism it may exhibit must be due to motion. Its great mass and rapid linear velocity of rotation should produce a magnetic field much stronger than that of the earth. Finally, the presence in its atmosphere of glowing gases and the well-known effect of magnetism on light should enable us to explore its magnetic field even at the distance of the earth. The effects of ionization, probably small in the region of high pressure beneath the photosphere and marked in the solar atmos-phere, must be determined and allowed for. But with this important limitation the sun may be used by the physicist for an experiment which can not be performed in the best equipped laboratory.

Schuster, in the lecture already cited, remarked:

The form of the corona suggests a further hypothesis which, extravagant as it may appear at present, may yet prove to be true. Is the sun a magnet?

Summing up the situation in April, 1912, he repeated:

The evidence (whether the sun is a magnet) rests entirely on the form of certain rays of the corona, which—assuming that they indicate the path of pro-jecting particles—seem to be deflected as they would be in a magnetic field, but this evidence is not at all decisive.

There remained the possibility of an appeal to a conclusive test of magnetism—the characteristic changes it produces in light which originates in a magnetic field.

Before describing how this test has been applied, let us rapidly recapitulate some of the principal facts of terrestrial magnetism. You see upon the screen the image of a steel sphere (fig. 2), which has been strongly magnetized. If iron filings are sprinkled over the glass plate that supports it, each minute particle becomes a mag-net under the influence of the sphere. When the plate is tapped, to relieve the friction, the particles fall into place along the lines of force, revealing a characteristic pattern of great beauty. A small compass needle, moved about the sphere, always turns so as to point along the lines of force. At the magnetic poles it points toward the center of the sphere. Midway between them, at the equator, it is parallel to the diameter joining the poles.

As the earth is a magnet it should exhibit lines of force resembling those of the sphere. If the magnetic poles coincided with the poles of rotation, a freely suspended magnetic needle should point ver-tically downward at one pole, vertically upward at the other, and horizontally at the equator. A dip needle, used to map the lines of force of the earth, is shown on the screen. I have chosen for illustration an instrument designed for use at sea, on the non-magnetic yacht *Carnegie*,[1] partly because the equipment used by

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[1] Illustrated in article on The Earth's Magnetism, by Dr. Bauer, pp. 195–212 of this volume.

PLATE 1.
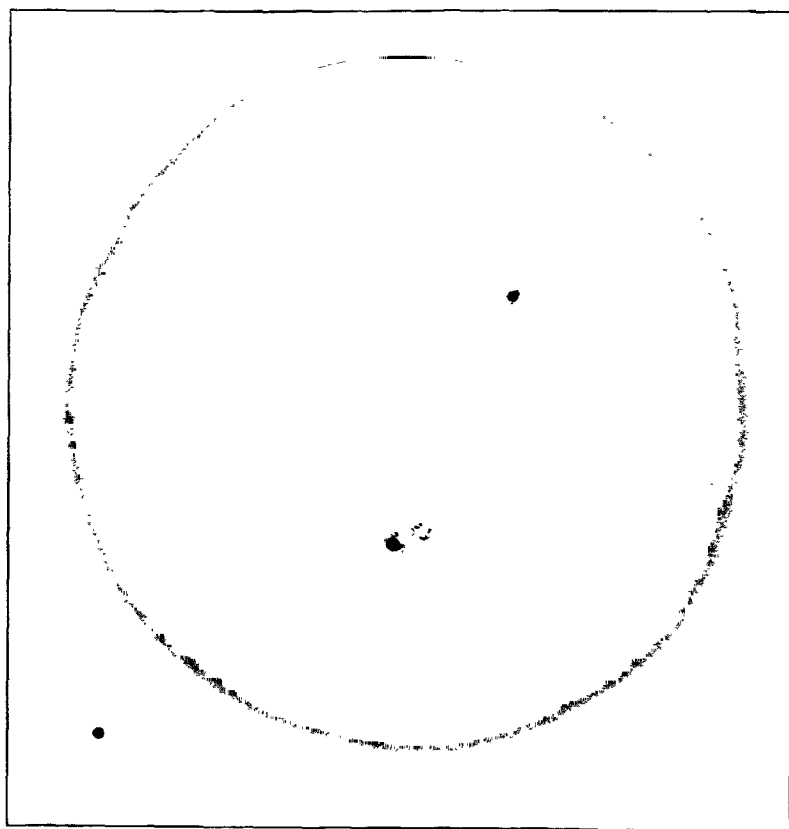
FIG. 1.—DIRECT PHOTOGRAPH OF THE SUN WITH DOT ONE MILLIMETER IN DIAMETER
(NEAR LOWER LEFT CORNER) REPRESENTING THE EARTH FOR COMPARISON
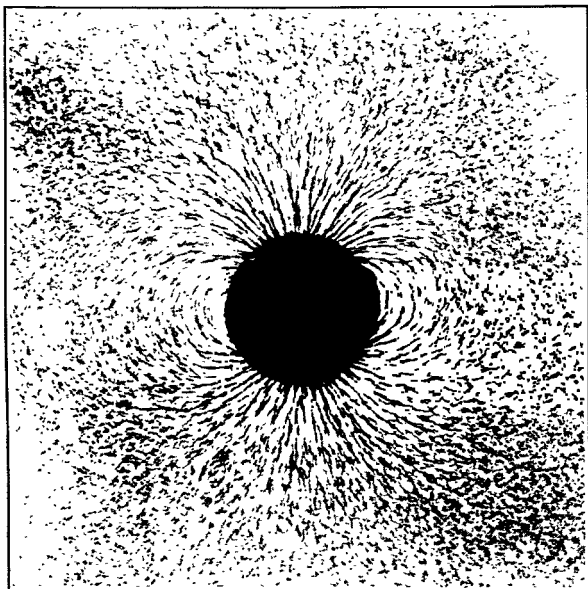
FIG. 2.—LINES OF FORCE OF A MAGNETIZED STEEL SPHERE.
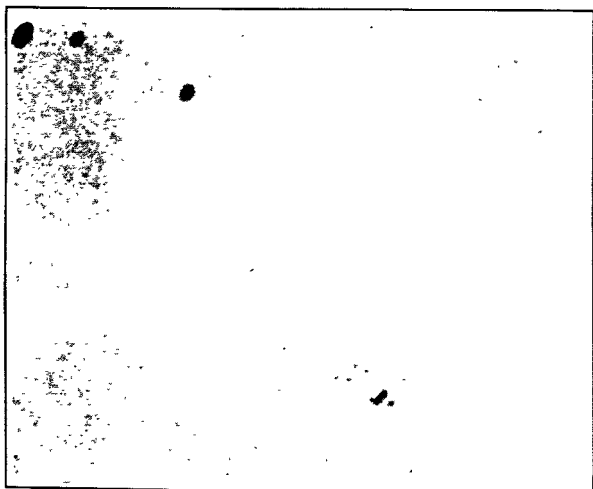
FIG. 3.—DIRECT PHOTOGRAPH OF PART OF THE SUN, APRIL 30, 1908.

Dr. Bauer in his extensive surveys represents the best now in use, and also because I wish to contrast the widely different means employed by the Carnegie Institution for the investigation of solar and terrestrial magnetic phenomena. The support of the dip needle is hung in gimbals, so that observations may be taken when the ship's deck is inclined. The smallest possible amount of metal enters into the construction of this vessel, and where its use could not be avoided, bronze was employed instead of iron or steel. She is thus admirably adapted for magnetic work, as is shown by the observations secured on voyages already totaling more than 100,000 miles. Her work is supplemented by that of land parties, bearing instruments to remote regions where magnetic observations have never before been made.

The dip needle clearly shows that the earth is a magnet, for it behaves in nearly the same way as the little needle used in our experiment with the magnetized sphere. But the magnetic poles of the earth do not coincide with the geographical poles. The north magnetic pole, discovered by Ross and last visited by Amundsen in 1903, lies near Baffins Bay, in latitude 70° north, longitude 97° west. The position of the south magnetic pole, calculated from observations made in its vicinity by Capt. Scott, of glorious memory, in his expedition of 1901–1904, is 72° 50′ south latitude, 153° 45′ east longitude. Thus the two magnetic poles are not only displaced about 30° from the geographical poles; they do not even lie on the same diameter of the earth. Moreover, they are not fixed in position, but appear to be rotating about the geographical poles in a period of about 900 years. In addition to these peculiarities, it must be added that the dip needle shows the existence of local magnetic poles, one of which has recently been found by Dr. Bauer's party at Treadwell Point, Alaska. At such a place the direction of the needle undergoes rapid change as it is moved about the local pole.

The dip needle, as we have seen, is free to move in a vertical plane. The compass needle moves in a horizontal plane. In general, it tends to point toward the magnetic pole, and as this does not correspond with the geographical pole, there are not many places on the earth's surface where the needle indicates true north and south. Local peculiarities, such as deposits of iron ore, also affect its direction very materially. Thus a variation chart, which indicates the deviation of the compass needle from geographical north, affords an excellent illustration of the irregularities of terrestrial magnetism. The necessity for frequent and accurate surveys of the earth's magnetic field is illustrated by the fact that the *Carnegie* has found errors of 5° or 6° in the variation charts of the Pacific and Indian Oceans.

In view of the earth's heterogeneous structure, which is sufficiently illustrated by its topographical features, marked deviations from the

uniform magnetic properties of a magnetized steel sphere are not at all surprising. The phenomenon of the secular variation, or the rotation of the magnetic poles about the geographical poles, is one of the peculiarities toward the solution of which both theory and experiment should be directed.

Passing over other remarkable phenomena of terrestrial magnetism, we come to magnetic storms and auroras, which are almost certainly of solar origin.

Here is a photograph of part of the sun, as it appears in the telescope (fig. 3).[1] Scattered over its surface are sun spots, which increase and decrease in number in a period of about 11.3 years. It is well known that a curve, showing the number of spots on the sun, is closely similar to a curve representing the variations of intensity of the earth's magnetism. The time of maximum sun spots corresponds with that of reduced intensity of the earth's magnetism, and the parallelism of the two curves is too close to be the result of accident. We may therefore conclude that there is some connection between the spotted area of the sun and the magnetic field of the earth.

We shall consider a little later the nature of sun spots, but for the present we may regard them simply as solar storms. When spots are numerous the entire sun is disturbed, and eruptive phenomena, far transcending our most violent volcanic outbursts, are frequently visible. In the atmosphere of the sun, gaseous prominences rise to great heights. This one, reaching an elevation of 85,000 miles, is of the quiescent type, which changes gradually in form and is abundantly found at all phases of the sun's activity. But such eruptions as the one of March 25, 1895, photographed with the spectroheliograph of the Kenwood Observatory, are clearly of an explosive nature. As these photographs show, it shot upward through a distance of 146,000 miles in 24 minutes, after which it faded away.

When great and rapidly changing spots, usually accompanied by eruptive prominences, are observed on the sun, brilliant displays of the aurora (fig. 6) and violent magnetic storms are often reported. The magnetic needle, which would record a smooth straight line on the photographic film if it were at rest, trembles and vibrates, drawing a broken and irregular curve. Simultaneously, the aurora flashes and pulsates, sometimes lighting up the northern sky with the most brilliant display of red and green discharges.

Birkeland and Störmer have worked out a theory which accounts in a very satisfactory way for these phenomena. They suppose that electrified particles, shot out from the sun with great velocity, are drawn in toward the earth's magnetic poles along the lines of force. Striking the rarified gases of the upper atmosphere, they illuminate

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[1] Figs. 3, 4, and 5 represent the same region of the sun, photographed at successively higher levels.

them, just as the electric discharge lights up a vacuum tube. There is reason to believe that the highest part of the earth's atmosphere consists of rarified hydrogen, while nitrogen predominates at a lower level. Some of the electrons from the sun are absorbed in the hydrogen, above a height of 60 miles. Others reach the lower-lying nitrogen, and descend to levels from 30 to 40 miles above the earth's surface. Certain still more penetrating rays sometimes reach an altitude of 25 miles, the lowest hitherto found for the aurora. The passage through the atmosphere of the electrons which cause the aurora also gives rise to the irregular disturbances of the magnetic needle observed during magnetic storms.

The outflow of electrons from the sun never ceases, if we may reason from the fact that the night sky is at all times feebly illuminated by the characteristic light of the aurora. But when sun spots are numerous, the discharge of electrons is most violent, thus explaining the frequency of brilliant auroras and intense magnetic storms during sun-spot maxima. It should be remarked that the discharge of electrons does not necessarily occur from the spots themselves, but rather from the eruptive regions surrounding them.

Our acquaintance with vacuum-tube discharges dates from an early period, but accurate knowledge of these phenomena may be said to begin with the work of Sir William Crookes in 1876. A glass tube, fitted with electrodes, and filled with any gas, is exhausted with a suitable pump until the pressure within it is very low. When a high-voltage discharge is passed through the tube, a stream of negatively charged particles is shot out from the cathode, or negative pole, with great velocity. These electrons, bombarding the molecules of the gas within the tube, produce a brillant illumination, the character of which depends upon the nature of the gas. The rare hydrogen gas in the upper atmosphere of the earth, when bombarded by electrons from the sun, glows like the hydrogen in this tube. Nitrogen, which is characteristic of a lower level, shines with the light which can be duplicated here.

But it may be remarked that this explanation of the aurora is only hypothetical, in the absence of direct evidence of the emission of electrons by the sun. However, we do know that hot bodies emit electrons. Here is a carbon filament in an exhausted bulb. When heated white hot a stream of electrons passes off. Falling upon this electrode the electrons discharge the electroscope with which it is connected. Everyone who has to discard old incandescent lamps is familiar with the result of this outflow. The blackening of the bulbs is due to finely divided carbon carried away by the electrons and deposited upon the glass.

Now, we know that great quantities of carbon in a vaporous state exist in the sun and that many other substances also present there

emit electrons in the same way. Hence we may infer that electrons are abundant in the solar atmosphere.

The temperature of the sun is between 6,000° and 7,000° C., twice as high as we can obtain by artificial means. Under solar conditions, the velocity of the electrons emitted in regions where the pressure is not too great may be sufficient to carry them to the earth. Arrhenius holds that the electrons attach themselves to molecules or groups of molecules and are then driven to the earth by light pressure.

In certain regions of the sun we have strong evidence of the existence of free electrons. This leads us to the question of solar magnetism and suggests a comparison of the very different conditions in the sun and earth. Much alike in chemical composition, these bodies differ principally in size, in density, and in temperature. The diameter of the sun is more than 100 times that of the earth, while its density is only one-quarter as great. But the most striking point of difference is the high temperature of the sun, which is much more than sufficient to vaporize all known substances. This means that no permanent magnetism, such as is exhibited by a steel magnet or a lodestone, can exist in the sun. For if we bring this steel magnet to a red heat it loses its magnetism and drops the iron bar which it previously supported. Hence, while some theories attribute terrestrial magnetism to the presence within the earth of permanent magnets, no such theory can apply to the sun. If magnetic phenomena are to be found there they must result from other causes.

The familiar case of the helix illustrates how a magnetic field is produced by an electric current flowing through a coil of wire. But according to the modern theory, an electric current is a stream of electrons. Thus a stream of electrons in the sun should give rise to a magnetic field. If the electrons were whirled in a powerful vortex, resembling our tornadoes or waterspouts, the analogy with the wire helix would be exact, and the magnetic field might be sufficiently intense to be detected by spectroscopic observations.

A sun spot, as seen with a telescope or photographed in the ordinary way, does not appear to be a vortex. If we examine the solar atmosphere above and about the spots, we find extensive clouds of luminous calcium vapor, invisible to the eye, but easily photographed with the spectroheliograph by admitting no light to the sensitive plate except that radiated by calcium vapor. These calcium flocculi (fig. 4), like the cumulus clouds of the earth's atmosphere, exhibit no well-defined linear structure. But if we photograph the sun with the red light of hydrogen, we find a very different condition of affairs (fig. 5). In this higher region of the solar atmosphere, first photographed on Mount Wilson in 1908, cyclonic whirls, centering in sun spots, are clearly shown.
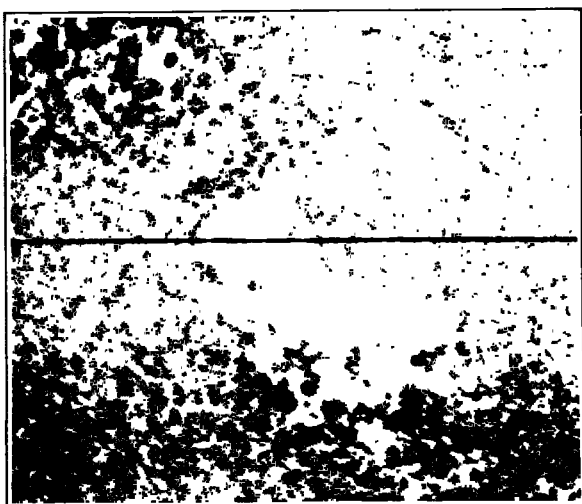
FIG. 4.—SAME REGION OF THE SUN SHOWING THE CALCIUM
(H_2) FLOCCULI.
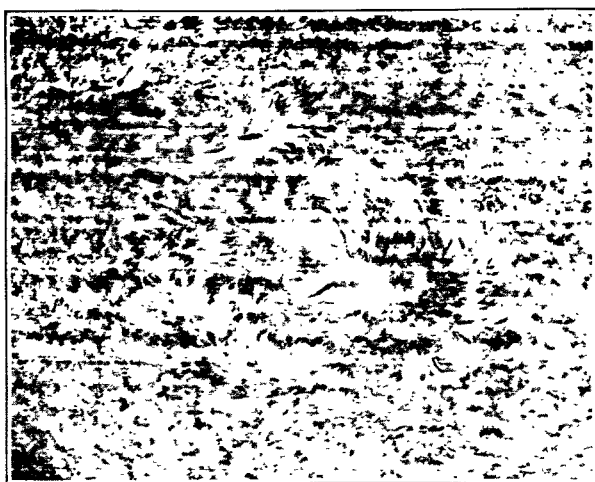
FIG. 5.—SAME REGION OF THE SUN SHOWING THE HYDROGEN
(H_a) FLOCCULI.

PLATE 4.

FIG. 6.—THE AURORA.

FIG. 7.—WATER SPOUT.

The idea that sun spots may be solar tornadoes, which was strongly suggested by such photographs, soon received striking confirmation. A great cloud of hydrogen, which had hung for several days on the edge of one of these vortex structures, was suddenly swept into the spot at a velocity of about 60 miles per second. More recently Slocum has photographed at the Yerkes Observatory a prominence at the edge of the sun, flowing into a spot with a somewhat lower velocity.

Thus we were led to the hypothesis that sun spots are closely analogous to tornadoes or waterspouts in the earth's atmosphere (fig. 7). If this were true, electrons caught and whirled in the spot vortex should produce a magnetic field. Fortunately, this could be put to a conclusive test through the well-known influence of magnetism on light discovered by Zeeman in 1896.

In Zeeman's experiment a flame containing sodium vapor was placed between the poles of a powerful electromagnet. The two yellow sodium lines, observed with a spectroscope of high dispersion, were seen to widen the instant a magnetic field was produced by passing a current through the coils of the magnet. It was subsequently found that most of the lines of the spectrum, which are single under ordinary conditions, are split into three components when the radiating source is in a sufficiently intense magnetic field. This is the case when the observation is made at right angles to the lines of force. When looking along the lines of force, the central line of such a triplet disappears (fig. 8), and the light of the two side components is found to be circularly polarized in opposite directions. With suitable polarizing apparatus, either component of such a line can be cut off at will, leaving the other unchanged. Furthermore, a double line having these characteristic properties can be produced only by a magnetic field. Thus it becomes a simple matter to detect a magnetic field at any distance by observing its effect on light emitted within the field. If a sun spot is an electric vortex, and the observer is supposed to look along the axis of the whirling vapor, which would correspond with the direction of the lines of force, he should find the spectrum lines double, and be able to cut off either component with the palarizing attachment of his spectroscope.

I applied this test to sun spots on Mount Wilson in June, 1908, with the 60-foot tower telescope, and at once found all of the characteristic features of the Zeeman effect. Most of the lines of the sun-spot spectrum are merely widened by the magnetic field, but others are split into separate components (fig. 9), which can be cut off at will by the observer. Moreover, the opportune formation of two large spots, which appeared on the spectroheliograph plates to be rotating in opposite directions (fig. 10), permitted a still more exacting experiment to be tried. In the laboratory, where the polar-

izing apparatus is so adjusted as to transmit one component of a line doubled by a magnetic field, this disappears and is replaced by the other component when the direction of the current is reversed. In other words, one component is visible alone when the observer looks toward the north pole of the magnet, while the other appears alone when he looks toward the south pole. If electrons of the same kind are rotating in opposite directions in two sun-spot vortexes, the observer should be looking toward a north pole in one spot and toward a south pole in the other. Hence the opposite components of a magnetic double line should appear in two such spots. As our photographs show, the result of the test was in harmony with my anticipation.

I may not pause to describe the later developments of this investigation, though two or three points must be mentioned. The intensity of the magnetic field in sun spots is sometimes as high as 4,500 gausses, or 9,000 times the intensity of the earth's field. In passing upward from the sun's surface the magnetic intensity decreases very rapidly—so rapidly, in fact as to suggest the existence of an opposing field. It is probable that the vortex which produces the observed field is not the one that appears on our photograph, but lies at a lower level. In fact, the vortex structure shown on spectroheliograph plates may represent the effect rather than the cause of the sun-spot field. We may have, as Brester and Deslandres suggest, a condition analogous to that illustrated in the aurora: Electrons, falling in the solar atmosphere, move along the lines of force of the magnetic field into spots. In this way we may perhaps account for the structure surrounding pairs of spots, of opposite polarity, which constitute the typical sun-spot group. The resemblance of the structure near these two bipolar groups to the lines of force about a bar magnet is very striking. especially when the disturbed condition of the solar atmosphere. which tends to mask the effect, is borne in mind. It is not unlikely that the bipolar group is due to a single vortex, of the horseshoe type, such as we may see in water after every sweep of an oar.

We thus have abundant evidence of the existence on the sun of local magnetic fields of great intensity—fields so extensive that the earth is small in comparison with many of them. But how may we account for the copious supply of electrons needed to generate the powerful currents required in such enormous electromagnets? Neutral molecules, postulated in theories of the earth's field, will not suffice. A marked preponderance of electrons of one sign is clearly indicated.

An interesting experiment, due to Harker, will help us here. Imagine a pair of carbon rods insulated within a furnace heated to a temperature of two or three thousand degrees. The outer ends of

PLATE 5.
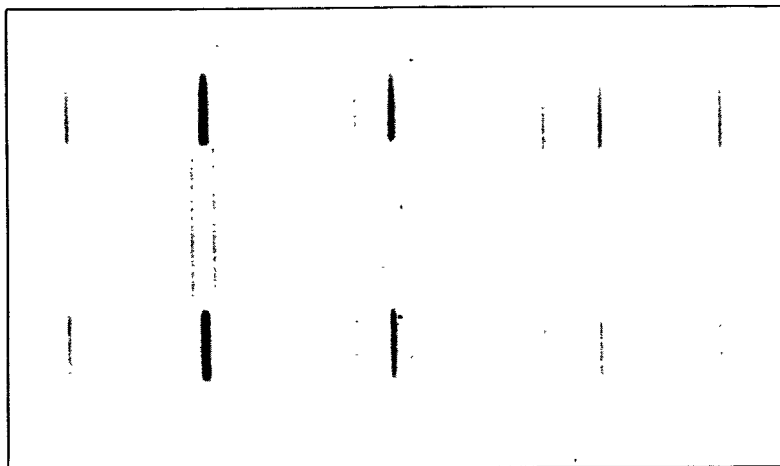
FIG. 8.—ZEEMAN DOUBLET PHOTOGRAPHED IN LABORATORY SPECTRUM

The middle section shows the doublet. The adjacent sections indicate the appearance of the spectrum line in the absence of a magnetic field.
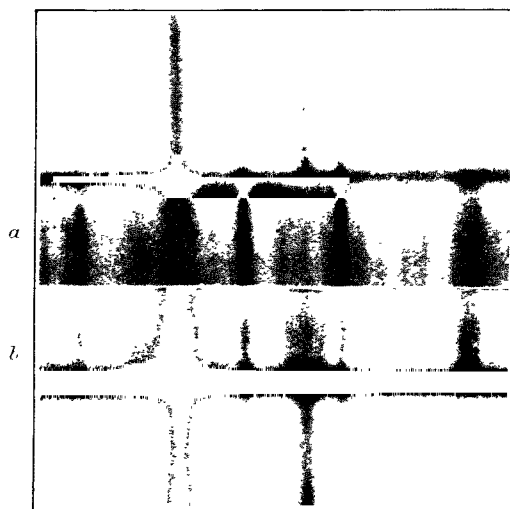
FIG. 9.—a, b, SPECTRA OF TWO SUN SPOTS

The triple line indicates a magnetic field of 4,700 gausses in a and of 2,900 gausses in b.

PLATE 6.
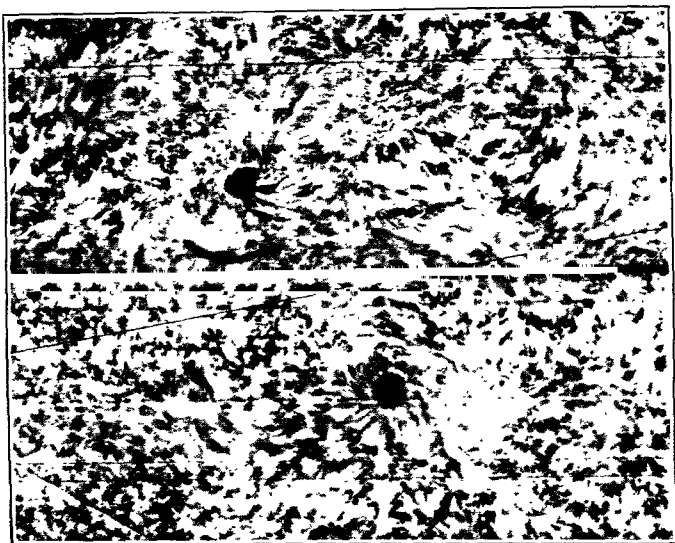
FIG. 10.—RIGHT AND LEFT HANDED VORTEXES SURROUNDING SUN
SPOTS, AS INDICATED BY THE DISTRIBUTION OF HYDROGEN GAS.

Photographed with the spectroheliograph
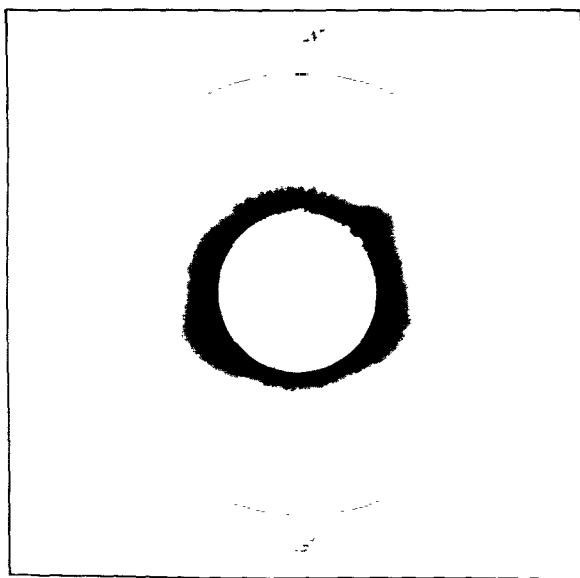
FIG. 11.—SOLAR CORONA SHOWING POLAR STREAMERS.

the rods projecting from the furnace are connected to a galvanometer. Harker found that when one of the carbon terminals within the furnace was cooler than the other a stream of negative electrons flowed toward it from the hotter electrode. Even at atmospheric pressure currents of several amperes were produced in this way.[1]

Our spectroscopic investigations, interpreted by laboratory experiments, are in harmony with those of Fowler in proving that sun spots are comparatively cool regions in the solar atmosphere. They are hot enough, it is true, to volatilize such refractory elements as titanium, but cool enough to permit the formation of certain compounds not found elsewhere in the sun. Hence, from Harker's experiment, we may expect a flow of negative electrons toward spots. These, caught and whirled in the vortex, would easily account for the observed magnetic fields.

The conditions existing in sun spots are thus without any close parallel among the natural phenomena of the earth. The sun-spot vortex is not unlike a terrestial tornado, on a vast scale, but if the whirl of ions in a tornado produces a magnetic field, it is too feeble to be readily detected. Thus, while we have demonstrated the existence of solar magnetism, it is confined to limited areas. We must look further if we would throw new light on the theory of the magnetic properties of rotating bodies.

This leads us to the question with which we started: Is the sun a magnet, like the earth? The structure of the corona, as revealed at total eclipses, points strongly in this direction. Remembering the lines of force of our magnetized steel sphere, we can not fail to be struck by their close resemblance to the polar streamers in these beautiful photographs of the corona (fig. 11) taken by Lick Observatory eclipse parties, for which I am indebted to Prof. Campbell. Bigelow, in 1889, investigated this coronal structure and showed that it is very similar to the lines of force of a spherical magnet. Störmer, guided by his own researches on the aurora, has calculated the trajectories of electrons moving out from the sun under the influence of a general magnetic field and compared these trajectories with the coronal streamers. The resemblance is apparently too close to be the result of chance. Finally, Deslandres has investigated the forms and motion of solar prominences, which he finds to behave as they would in a magnetic field of intensity about one-millionth that of the earth. We may thus infer the existence of a general solar magnetic field. But since the sign of the charge of the outflowing electrons is not certainly known, we can not determine the polarity of the sun in this way. Furthermore, our present uncertainty as to the proportion at different levels of positive and negative electrons and of the

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[1] King has recently found that the current decreases very rapidly as the pressure increases, but is still appreciable at a pressure of 20 atmospheres.

perturbations due to currents in the solar atmosphere must delay the most effective application of these methods, though they promise much future knowledge of the magnetic field at high levels in the solar atmosphere.

Of the field at low levels, however, they may tell us little or nothing, for the distribution of the electrons may easily be such as to give rise to a field caused by the rotation of the solar atmosphere, which may oppose in sign the field due to the rotation of the body of the sun. To detect this latter field, the magnetic field of the sun as distinguished from that of the sun's atmosphere, we must resort to the method employed in the case of sun spots—the study of the Zeeman effect. If this is successful it will not only show beyond doubt whether the sun is a magnet; it will also permit the polarity of the sun to be compared with that of the earth, gives a measure of the strength of the field at different latitudes and indicate the sign of the charge that a rotating sphere must possess if it is to produce a similar field.

I first endeavored to apply this test with the 60-foot tower telescope in 1908, but the results were too uncertain to command confidence.

Thanks to additional appropriations from the Carnegie Institute of Washington, a new and powerful instrument was available on Mount Wilson for a continuation of the investigation in January, 1912. The new tower telescope has a focal length of 150 feet (fig. 12). To prevent vibration in the wind, the cœlostat, second mirror, and object glass are carried by a skeleton tower, each vertical and diagonal member of which is inclosed within the corresponding member of an outer skeleton tower, which also carries a dome to shield the instruments from the weather. In the photograph we see only the hollow members of the outer tower. But within each of them, well separated from possible contact, a sectional view would show the similar but more slender members of the tower that support the instruments. The plan has proved to be successful, permitting observations demanding the greatest steadiness of the solar image to be made.

The arrangements are similar to those of the 60-foot tower. The solar image. $16\frac{1}{2}$ inches in diameter, falls on the slit of a spectrograph (fig. 13) in the observation house at the ground level. The spectrograph, of 75 feet focal length, enjoys the advantage of great stability and constancy of temperature in its subterranean vault beneath the tower. In the third order spectrum, used for this investigation, the D lines of the solar spectrum are 29 millimeters apart. The resolving power of the excellent Michelson grating is sufficient to show 75 lines of the iodine absorption spectrum in this space between the D's. Thus the instruments are well suited for
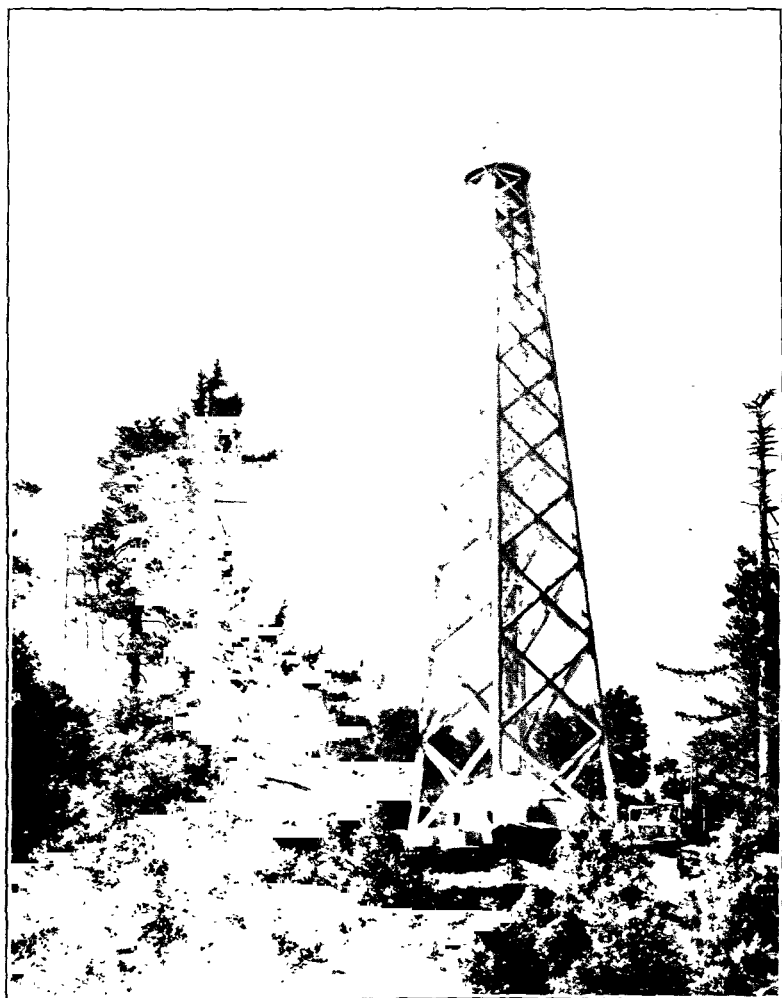
FIG 12.—150-FOOT TOWER TELESCOPE.
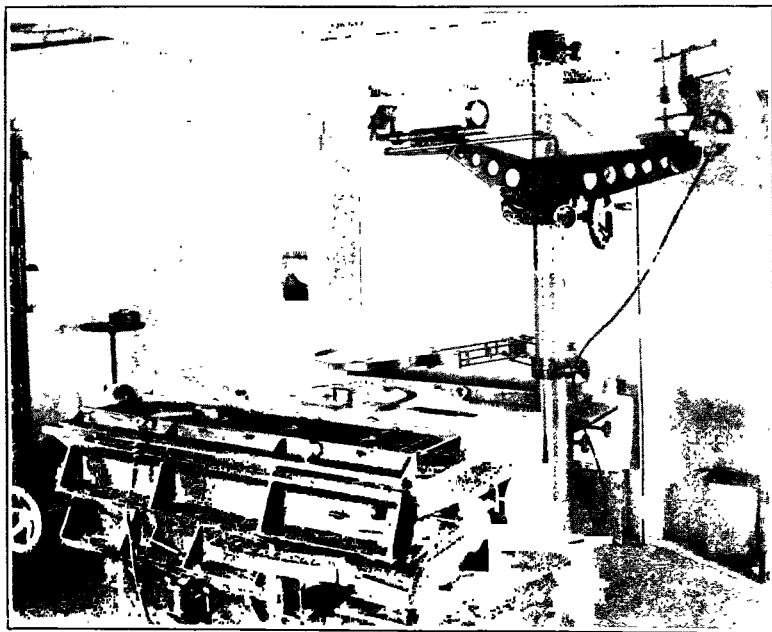
FIG. 13.—HEAD OF THE 75-FOOT SPECTOGRAPH OF THE 150-FOOT TOWER
TELESCOPE.
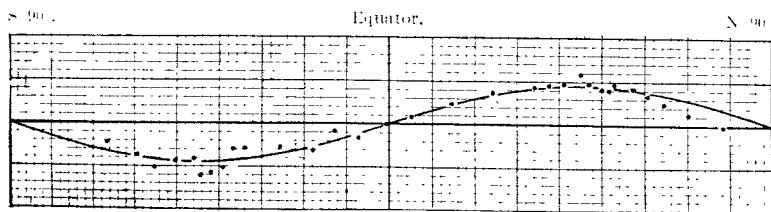
FIG. 14.—THE CURVE REPRESENTS THE THEORETICAL VARIATION OF THE DIS-
PLACEMENTS OF SPECTRUM LINES WITH THE HELIOGRAPHIC LATITUDE.

The sun is assumed to be a magnetic sphere with its magnetic poles coinciding with the
poles of rotation   The points represent mean values of the observed displacements.
Vertical scale   1 square = 0.001 mm = 0.0002 Angstrom.

the exacting requirements of a difficult investigation. For it must be borne in mind that the problem is very different from that of detecting the magnetic fields in sun spots, where the separation of the lines is from 50 to 100 times as great as we may expect to find here. Thus the sun's general field can produce no actual separation of the lines. But it may cause a very slight widening, which should appear as a displacement when suitable polarizing apparatus is used. This is so arranged as to divide the spectrum longitudinally into narrow strips. The component toward the red end of the spectrum of a line widened by magnetism should appear in one strip, the other component in the next strip. Hence, if the sun has a magnetic field of sufficient strength, the line should have a dentated appearance. The small relative displacements of the lines on successive strips, when measured under a microscope, should give the strength of the magnetic field.

The above remarks apply strictly to the case when the observer is looking directly along the lines of force. At other angles neither component is completely cut off, and the magnitude of the displacement will then depend upon two things: The strength of the magnetic field and the angle between the line of sight and the lines of force. Assuming that the lines of force of the sun correspond with those of a magnetized sphere, and also that the magnetic poles coincide with the poles of rotation, it is possible to calculate what the relative displacement should be at different solar latitudes. These theoretical displacements are shown graphically by the sine curve on the screen (fig. 14).

We see from the curve that the greatest displacements should be found at 45° north and south latitude, and that from these points they should decrease toward zero at the equator and the poles. Furthermore, the curve shows that we may apply the same crucial test used in the case of sun spots; the direction of the displacements, toward red or violet, should be reversed in the northern and southern hemispheres.

I shall not trouble you with the details of the hundreds of photographs and the thousands of measures which have been made by my colleagues and myself during the past year. In view of the diffuse character of the solar lines under such high dispersion and the exceedingly small displacements observed, the results must be given with some reserve, though they appear to leave no doubt as to the reality of the effect. Observations in the second order spectrum failed to give satisfactory indications of the field. But with the higher dispersion of the third order 11 independent determinations, made with every possible precaution to eliminate bias, show opposite displacements in the northern and southern hemispheres decreasing in magnitude from about 45° north and south latitude to the equator.

Three of these determinations were pushed as close to the poles as conditions would permit, and the observed displacements may be compared with the theoretical curve (fig. 14). In view of the very small magnitude of the displacements, which never surpass 0.002 Angströms, the agreement is quite as satisfactory as one could expect for a first approximation.

The full details of the investigation are given in a paper recently published.[1] The reader will find an account of the precautions taken to eliminate error, and, I trust, no tendency to underestimate the possible adverse bearing of certain negative results. It must remain for the future to confirm or to overthrow the apparently strong evidence in favor of the existence of a true Zeeman effect, due to the general magnetic field of the sun. If this evidence can be accepted, we may draw certain conclusions of present interest.

Taking the measures at their face value, they indicate that the north magnetic pole of the sun lies at or near the north pole of rotation, while the south magnetic pole lies at or near the south pole of rotation. In other words, if a compass needle could withstand the solar temperature, it would point approximately as it does on the earth, since the polarity of the two bodies appears to be the same. Thus, since the earth and sun rotate in the same direction, a negative charge distributed through their mass would account in each case for the observed magnetic polarity.

As for the strength of the sun's field, only three preliminary determinations have yet been made, with as many different lines. Disregarding the systematic error of measurement, which is still very uncertain, these indicate that the field strength at the sun's poles is of the order of 50 gausses (about 80 times that of the earth).

Schuster, assuming the magnetic fields of the earth and sun to be due to their rotation, found that the strength of the sun's field should be 440 times that of the earth, or 264 gausses. This was on the supposition that the field strength of a rotating body is proportional to the product of the radius and the maximum linear velocity of rotation, but neglected the density. Before inquiring why the observed and theoretical values differ, we may glance at the two most promising hypotheses that have been advanced in support of the view that every large rotating body is a magnet.

On account of their greater mass, the positive electrons of the neutral molecules within the earth may perhaps be more powerfully attracted by gravitation than the negative electrons. In this case the negative charge of each molecule should be a little farther from the center of the earth than the positive charge. The average linear velocity of the negative charge would thus be a little greater, and the magnetizing effect due to its motion would slightly exceed that

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[1] Contributions from the Mount Wilson Solar Observatory, No. 71.

due to the motion of the positive charge. By assuming a separation of the charges equal to about four-tenths the radius of a molecule (Bauer), the symmetrical part of the earth's magnetic field could be accounted for as the result of the axial rotation.

This theory, first suggested by Thomson, has been developed by Sutherland, Schuster, and Bauer. But as yet it has yielded no explanation of the secular variation of the earth's magnetism, and the merits of other theories must not be overlooked.

Chief among these is the theory that rests on the very probable assumption that every molecule is a magnet. If the magnetism is accounted for as the effect of the rapid revolution of electrons within the molecule, a gyrostatic action might be anticipated. That is, each molecule would tend to set itself with its axis parallel to the axis of the earth, just as the gyrostatic compass, now coming into use at sea, tends to point to the geographical pole. The host of molecular magnets, all acting together, might account for the earth's magnetic field.

This theory, in its turn, is not free from obvious points of weakness, though they may disappear as the result of more extended investigation. Its chief advantage lies in the possibility that it may explain the secular variation of the earth's magnetism by a precessional motion of the magnetic molecules.

On either hypothesis, it is assumed, in the absence of knowledge to the contrary, that every molecule contributes to the production of the magnetic field. Thus the density of the rotating body may prove to be a factor. Perhaps the change of density from the surface to the center of the sun must also be taken into account. But the observational results already obtained suggest that the phenomena of ionization in the solar atmosphere may turn out to be the predominant influence.

The lines which show the Zeeman effect originate at a comparatively low level in the solar atmosphere. Preliminary measures indicate that certain lines of titanium, which are widely separated by a magnetic field in the laboratory, are not appreciably affected in the sun. As these lines represent a somewhat higher level, it is probable that the strength of the sun's field decreases very rapidly in passing upward from the surface of the photosphere—a conclusion in harmony with results obtained from the study of the corona and prominences. Thus it may be found that the distribution of the electrons is such as to give rise to the observed field or to produce a field opposing that caused by the rotation of the body of the sun. It is evident that speculation along these lines may advantageously await the accumulation of observations covering a wide range of level. Beneath the photosphere, where the pressure is high, we may conclude from recent electric furnace experiments by King that free electrons, though relatively few, may nevertheless play some part in the production of the general magnetic field.

In this survey of magnetic phenomena we have kept constantly in mind the hypothesis that the magnetism of the earth is due to its rotation. Permanent magnets, formerly supposed to account for the earth's magnetic field, could not exist at the high temperature of the sun. Displays of the aurora, usually accompanied by magnetic storms, are plausibly attributed to electrons reaching the earth from the sun, and illuminating the rare gases of the upper atmosphere just as they affect those in a vacuum tube. Definite proof of the existence of free electrons in the sun is afforded by the discovery of powerful local magnetic fields in sun spots, where the magnetic intensity is sometimes as great as nine thousand times that of the earth's field. These local fields probably result from the rapid revolution in a vortex of negative electrons, flowing toward the cooler spot from the hotter region outside. The same method of observation now indicates that the whole sun is a magnet, of the same polarity as the earth. Because of the high solar temperature, this magnetism may be ascribed to the sun's axial rotation.[1] It is not improbable that the earth's magnetism also results from its rotation, and that other rotating celestial bodies, such as stars and nebulæ, may ultimately be found to possess magnetic properties. Thus, while the presence of free electrons in the sun prevents our acceptance of the evidence as a proof that every large rotating body is a magnet, the results of the investigation are not opposed to this hypothesis, which may be tested further by the study of other stars of known diameter and velocity of rotation.

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[1] The alternative hypothesis, that the sun's magnetism is due to the combined effect of numberless local magnetic fields, caused by electric vortices in the solar " pores," though at first sight improbable, deserves further consideration.

THE REACTION OF THE PLANETS UPON THE SUN.[1]

By P. Puiseux.[2]

Member of the Institute, Astronomer at the Paris Observatory.

The popular preconception that the earth, with the sun rotating about it, was the center of the universe, was overcome only through the persistent efforts of astronomers and physicists. We will not here review these memorable discussions, but will note merely the result. Everyone capable of connected and geometrical reasoning will become convinced that the position of the earth, face to face with the sun, is that of a humble satellite, and that our globe, forced to escort our daytime star in its mysterious course through space, receives from this star its law of annual movement and at the same time its indispensable ration of heat and light.

Going from one extreme to another, the sun was believed to be independent of the relatively minute planets which it carries along with itself. It seemed that a fictitious observer, placed at its center or on its surface, would have no occasion to suspect the existence of other celestial bodies. Further protected against any perceptible action from the stars by their immense distance, the sun must lavish its splendor, with no pay in return, and follow unperturbed its undeviated path through space.

THE INFLUENCE OF THE PLANETS ON THE MOTION OF THE SUN.

This conclusion was in some respects too radical. An account of this matter could be rendered only when the penetrating genius of Newton showed that the curved trajectory of a projectile, the revolution of the moon about the earth, and the revolution of the earth around the sun were three manifestations of the same law. This law holds everywhere. Further, it is not a special privilege of the center of any system. The bond exists, real though slight, between any two particles whatever. The sun, as well as the humblest planet, because of this bond, must undergo periodic variations in its speed as well as in its shape.

[1] Lecture delivered at the Conservatoire des Arts et Métiers, Feb. 23, 1913.
[2] Translated by permission from Revue Scientifique, Paris, May 3, 1913.

Have we to-day at our disposal sufficiently delicate means of observations to detect these changes? In Newton's time such means were probably lacking. The caprices of our atmosphere furnished a ready explanation of the apparent fluctuations in solar radiation. The spots had been observed on the sun's disk, sometimes few, sometimes many, but no law had been assigned to them. Further, the traditional fixity of the constellations led to the belief that the sun maintained a complete immobility with reference to the stars.

But the problem plainly stated aroused new attempts at its unraveling. Bradley, a fellow countryman and a disciple of Newton, showed that much greater precision could be obtained in the measures of the angular distances of the stars than had before been gained. Less than a century later, W. Herschel could affirm that the constellations do alter their form, and the best determination of these changes may be explained by attributing to the solar system a regular rectilinear motion. The ambition of astronomers, increasing with success, tries to-day to show that this movement is not rigorously uniform, and even though shielded from the action of the stars, pays tribute to the universal attraction in periodic oscillations.

It is pretty safe to predict what will be the most marked of these oscillations. It is not the center of the sun itself which possesses the uniform rectilinear motion, but the center of gravity of the system formed by the sun and all the planets. The oscillation would be small if only the earth need be considered. There is, however, a giant planet, Jupiter, whose mass exceeds that of all of the other planets taken together and is nearly one one-thousandth that of the sun. Describing its orbit at the rate of 12 kilometers per second, Jupiter forces the sun to rotate about an imaginary center with a velocity a thousand times less. This is apparently a very small amount, but not at all negligible with respect to the velocity of translation of the solar system, which is 20 kilometers per second. Consequently the speed of the solar system toward a point in the constellation Hercules is sometimes accelerated, sometimes slowed, by one part in one thousand in an interval of six years.

Very few of the stars are near enough to us for the parallactic displacement relative to the more distant stars and due to this motion of the sun to be appreciable in six years. Consequently, to measure one one-thousandth part of this displacement is beyond the resources of precise astronomy. We may be pretty sure, though, that some day we will thus obtain, at the same time with a measure of the mass of Jupiter, a new confirmation of the principle of the universal attraction of gravitation.

Meanwhile help comes in another way. What the micrometer for a long time will probably be unable to give, the spectroscope is already furnishing. Although the variation of 30 meters per second,

which we wish to detect in the motion of the sun, requires years to change sensibly the apparent position of a star, it takes only a moment to alter the quality of its light. Whatever the distance, the light waves will come to us sometimes more frequently, sometimes less; their path through a prism will consequently be found altered and the fine metallic lines of the spectrum recorded by a photograph will be displaced relatively to those of a stationary source, such as an electric spark used for comparison.

The earliest happy applications of this principle were due to Huggins and to Vogel. It was used to separate numerous double stars composed of pairs of suns so close to each other and so distant from us that each pair appeared as a single star. But the brightness of each was sufficient to record a spectrum and the relative velocities were sufficiently variable so that two spectrum lines of the same chemical origin separated periodically. Subsequently another class, yet greater in number, was found in which the spectrum lines were not doubled, but showed a periodic oscillation. In this case we may suppose that one of the two stars, while not bright enough to register its spectrum, is yet heavy enough to sway its associate. The period is usually several weeks or days. The displacements of the lines correspond to velocities of the same order as those of the planets, from 10 to 100 kilometers per second. Because of the extreme accuracy and care in the use of spectroscopes, certain astronomers can now measure velocities to a fraction of a kilometer.

The time will come when pairs like the sun and Jupiter can be detected, however distant they may be, provided only that the principal star is bright enough to record its spectrum. Campbell, who is the leader in this class of research, estimates that on the average one star in three will be found spectroscopically double. It is very probable that even more stars art double since we can see no reason why a planet like Jupiter should be exceptional. We may predict that all stellar spectra will be found thus variable even after correcting for the orbital movement of the earth. We may then gather photographic evidence of the existence of planets about the stars as well as the periodic oscillation of our sun due to Jupiter. The earth of course will produce a similar effect only less in amplitude and period. But who would dare to put a limit to the skill of our opticians or the patience of our astronomers in a path so definitely marked out?

THE PLANETS AS THE CAUSE OF THE SOLAR CYCLE.

To find that we disturb the sun is of course something to elate us. We will feel perhaps a more tangible satisfaction if we can find that we cause changes in the aspect of its surface, disturbances visible by direct and not indirect evidence in the field of the microscope.

We will now consider a deforming action dependent also on Newton's law but of a differential nature and consequently proportional to the inverse cube instead of the inverse square of the distance. This difference helps to compensate for the inferiority of the mass of the earth with reference to the greater planets and gives it a chance for an honorable rank in this contest.

We have under our eyes an encouraging phenomenon. The attraction at the surface of the earth due to the sun is but a small fraction compared to the weight of a body here, and the yet feebler attraction due to the moon can not lighten a body by one one-hundred thousandth part of its weight. Yet we see the moon exerting this power and indeed with three times more strength than is felt from the sun, in deforming our globe. This action can be detected upon the atmosphere, the oceans, and even the solid crust of the earth. The seas, however, are what render it most evident to our eyes. Under favorable conditions, for instance, in the Bay of Mount St. Michel, on the French coast, we see the sea following faithfully the passage of the moon across the meridan. The sea's level changes at the flood some 20 meters in a few hours, displacing the shoreline several kilometers. The work thus developed, if we could only put it to use economically, would be enough to render useless all our oil wells and all the engines in the world.

We may find that no planet is as favorably situated to trouble the sun as the moon is the earth. But perhaps we should not be so exacting. We see upon the sun no such liquid seas which might be made to extend or contract their domains. The weight there to be conquered is great, 27 times greater than here. Despite that, we see chances that the sun may react as actively, or even more actively, than the earth, under the action of a distant body. We are indeed led by several converging paths of reasoning to think that the surface layers of the sun are to a great depth formed of extremely tenuous mobile matter, little subject to the action of weight and all ready, consequently, to obey the least force.

A first piece of evidence along this line is the development of spots, rents which seem to appear in the luminous veil of the solar surface, reaching in a few days an extent of ten, twenty, or thirty thousand kilometers and disappearing with equal rapidity. In the spectrum of these spots there is an increase in the number and intensity of the absorption bands, leading us to think that various metallic molecules of considerable atomic weight are spouted out in torrents, carried along by currents of the lighter hydrogen.

More impressive yet is the appearance of protuberances—clouds which develop and remain at heights where they could not be sustained by the dense and refringent atmosphere. Much less bright

than the disk, they have a special spectrum and during total eclipses are the principal source of light. We can now photograph them at any time about the edge of the disk by an ingenious method devised in 1868 by Janssen and by Lockyer and since singularly perfected. On many occasions we have been assured by incontestable evidence that protuberances can mount in a few hours in the form of vertical jets, narrow at the base to prodigious heights—50,000 to 100,000 kilometers or even more. Generally, however, before attaining such heights the protuberances expand into sheaves or stratified layers. At times they seem to be the seat of violent explosions, are scattered, and disappear very quickly. The spectroscope shows us that calcium vapor, despite its atomic weight 40 times heavier than that of hydrogen, rises very high in the protuberances. The displacements of the spectrum lines also furnish confirmation of the enormous velocities (100 kilometers or more per second) which the deformations of the contours suggest.

Total eclipses, during which protuberances first attracted attention, are even now the only occasions when we can see another interesting phase of solar activity—the solar corona. Sometimes it appears as a halo somewhat equally distributed around the disk, at other times as gigantic streamers stretching out distances several times the diameter of the sun. The forms of these rays indicate that the matter of which they are composed shows no haste in falling back into the sun. This matter is evidently very sparse and has very little absorptive action on light, for, despite its irregular distribution, it causes no difference in the appearance of the various parts of the disk. Its mobility must be very great since in the interval of two or three years between eclipses its structure completely changes, as our photographs assure us.

Spots, protuberances, and corona are subject to a great variation which takes place regularly about nine times in a century. After a period when the sun's disk appears entirely immaculate, spots reappear in both hemispheres at latitudes from 20° to 30°, then, always increasing, they invade the equatorial regions, becoming at the maximum 20 times more numerous on the average than in a minimum year. Then, as the decline commences, the numerical predominance, which the Northern Hemisphere at first seemed to show, passes to the Southern Hemisphere. The spots first disappear in the high latitudes and then diminish all over the sun.

The protuberances pass through a similar cycle, except that during the period while their number increases their mean latitude tends to increase in each hemisphere. Toward the epoch of spot maximum, and only then, it is not rare to see great protuberances even near the poles, where spots never appear.

The corona during the same period always undergoes a definite evolution. Toward the epoch of sun-spot minimum the polar rays are fine and vertical like the bristles of a brush. The jets in the middle and mean latitudes are much longer and bent toward the Equator. At the maximum period there is little difference with the latitude. During the transition years the poles and the Equator are almost clear and the rays are developed only in the middle latitudes, giving the whole a rectangular appearance.

The more we reflect upon these facts the less are we led to regard the sun as a monarch, inaccessible, and shut up in a tower of ivory. It, like the earth, must have seasons connected with the revolution of the planets and tides connected with its own rotation. To sift out at least the more active of these external influences is a legitimate task, even though it is not an easy one.

First, do we find one or several bodies which could be held responsible for a cycle of 11 years? The stars seem to be beyond consideration, since in that period there is no appreciable change in their linear or angular distances.

We could, as did John Herschel, blame one or several swarms of meteors, imagined for the purpose. Describing very eccentric orbits, they might graze the surface of the sun, causing the spots. Suitably choosing their revolution periods, inclinations, eccentricities, and the distribution of the matter in their orbits, we could explain the phenomenon in all its details. We must confess that the permanence of swarms of meteors put every 11 years to such a violent test does not seem probable. There is no doubt that meteors fall into the sun in great numbers. But we have no direct proof that this happens periodically and so as to produce visible effects. Such proof we feel that we must demand for this very supple and convenient hypothesis. As these swarms have not been detected, we must leave them and direct our investigations to the planets.

The most important of these planets brings a coincidence at first sight very seductive. Nearly every 11 years Jupiter, in a determinate sense, crosses the plane of the solar equator; also in every 11 years the numerical predominance of the spots passes from the northern to the southern hemisphere of the sun. The same interval separates the return of Jupiter to its least distance from the sun and the return of the sun-spot numbers to their extreme value.

We must not hurry, though, to sing our victory. It is not an approximate concordance but a precise one which we should demand. The periods in years are 11.86 for the revolution of Jupiter and 11.13 for the sun-spot cycle. For the second period, which is less well defined, the incertitude is in the hundredths. For more than a century we have careful records of spot numbers which reappear regularly. Now, in the course of a century the difference of eight

months between the periods brings them from complete coincidence to an absolute discordance. What now remains of our hoped-for proof if the nearest approach of the planet must sometimes condition an increase of spots, sometimes their disappearance?

We may suppose that Jupiter's action, though preponderant, is modified by a somewhat slower disturbing force which increases the interval between successive maxima. But the statistics of the number and extent of the spots, analyzed with the view of finding such a force, assigns to it such a long period that we have no clue as to its origin. A priori the most probable disturbing body would seem to be Saturn. It must act in the same sense as Jupiter, although to less extent. The spot maxima or minima should be particularly pronounced when the two planets are in conjunction with the sun—that is, every 20 years. Here again the evidence is negative.

We get an even less favorable answer from the rest of the planets. Either their revolution periods are too short to render an account of an 11-year fluctuation or their distances too great for their action to be sensible compared with that of Jupiter.

THE PLANETS AS A DISTURBING ELEMENT IN THE SOLAR CYCLE.

No planet, then, or combination of planets seems to be the principal cause of the solar cycle. We may, however, suppose that this or that planet may for a brief time trouble the cycle by rendering the distribution of spots irregular in longitude.

The sun rotates with reference to the fixed stars once in 25 days. The planets revolve about it in the same direction, but more slowly. Therefore, to an observer on the sun, the successive passages of a planet over his meridian occur in periods somewhat longer than 25 days, tending to approach this (sideral revolution) as the planet's distance increases. This is called the synodical rotation. That corresponding to the transit of the earth is 27.35 days.

Considering now the extreme mobility of the solar surface, we will see whether each planet does not produce a tidal wave which passes over the sun's surface with the corresponding synodical rotation period and capable of producing visible disturbances.

According to the elementary law of Newton, the relative importance of the tidal waves for the various planets is given by what we may call the deforming factor, the product of the mass by the inverse cube of the distance. If we make the value of this factor unity for the earth, the mean values for the planets are as follows:

Mercury	1.04	Jupiter	2.20
Venus	2.09	Saturn	.106
Earth	1.00	Uranus	.019
Mars	.03	Neptune	.001

We see that the most active cause for a tidal wave lies in Jupiter, followed closely by Venus. Mercury and the earth come next, the remaining planets being much less active.

Although the earth comes only in the fourth rank, we will consider it first because we are better situated for examining its effects. At each instant we can consider the sun as divided into two equal hemispheres, one visible, the other not. The limiting meridians turn uniformly over the surface of the sun in 27.35 days, the synodical period.

Let us first suppose that the earth has no physical influence on the development of the spots. The ratio between the total sun-spot areas in the two hemispheres may happen to have any value whatever; but the mean value taken over a long period of time embracing many synodical rotations, say for a whole solar-spot cycle, should differ very little from unity.

We can not at any given moment count or measure the spots on the invisible hemisphere. But we can count the spots which appear on the eastern border and compare these with those which disappear in the corresponding time limit at the western border. The ratio of the two numbers would have a tendency to surpass unity if it is at a time of decrease in spots and to be less than unity if in the increasing phase. But taken over a whole cycle, the mean value should differ very little from unity.

Now, let us suppose that the earth does have a physical influence, for instance, to fix our attention, that the presence of the earth above the horizon of some point on the sun favors the development of a spot at that point. As this development is certainly not instantaneous, any more than is its disappearance, more spots will be born in the visible hemisphere than in the opposite one. Consequently, more spots will disappear over the western border than appear at the eastern. The inverse inequality will be observed, provided we observe over a sufficiently long period, if the presence of the earth causes the disappearance of spots.

Instead of comparing the eastern with the western border we could compare the two halves of the visible disk, the right with the left, and the result would be equally decisive. Practically, if the action of the earth on the solar surface is real, the action will necessarily take a certain time to become manifest. Considerable masses must be moved, masses doubtless subject to interior friction. It is so relative to terrestrial tides which at any point of the earth suffer a variable retardation, but always very marked with reference to the passage of the moon over the meridian. If the earth has no influence, the two halves—the right and left—would, if considered over a sufficient time, show the same number and same area of spots. If the earth has a real influence there will be found a persistent and systematic inequality.

RESEARCHES OF MRS. MAUNDER, 1907.

Mrs. Maunder undertook to answer this question, utilizing the photographs due to a cooperation of English observatories for the interval 1889 to 1901, extending from one spot minimum to the next. At the beginning and the end the sun seemed absolutely free from spots. In every instance the rare survivors which could be found at the beginning and the end of the period upon the visible hemisphere could not vitiate the conclusions derived from all the observations.

The tables obtained at Greenwich comprised—

(1) The positions and areas of the groups for each day.

(2) The history, day by day, of each important group; the areas are expressed in millionths of the visible hemisphere and are corrected for the effect of perspective; the mean duration of a group is about six days; 2,870 groups were studied.

Mrs. Maunder divided the visible hemisphere at each instant into 14 vertical zones, each 13.2° wide and numbered in the inverse order of their appearance. For each zone and the entire period the sum representing the area of the spots was made. These results were compared for zones symmetrical to the central meridian. There was thus made manifest a systematic variation from two points of view:

(1) Despite the perspective correction, there was a constant progression on each side in passing from the limb to the central zone, as if the perspective correction had been insufficient.

(2) For each pair of zones there was a constant decrease in passing from the eastern to the corresponding western zone. The same thing was noted when in a similar manner the northern and southern hemispheres were treated separately.

Various reasons make the measures on the extreme zones less trustworthy, but even if we omit them the same conclusions result. If refraction in the solar atmosphere plays a part it would unduly enrich the extreme zones. Accordingly, if a correction is made for it, it but increases the first anomaly. Neither anomaly can be due to errors of observation or reduction.

If we do not like this process of treatment we need not depend upon the areas of the spots but count simply the number of groups visible in each zone, omitting those of long life which necessarily appear in both halves. Here again, for all pairs of zones, the eastern one shows a greater number than its corresponding western one.

We next ask whether there is, either in the visible or in the invisible half, an habitual and systematic excess in the number of spot births over deaths. A priori, it seems as if it must be so for one or the other hemisphere during the phase of increasing spots, but that an equilibrium must be established when a complete cycle is considered.

To throw light on this point Mrs. Maunder associated on each half of the disk the two extreme zones and compared the number of groups of spots which had been seen in each of the two double zones. The predominance was clearly in the eastern pair. There are throughout a cycle more spots seen near the eastern border, and consequently for the whole visible hemisphere and whole cycle there is an excess of disappearances over appearances of spots. The opposite must hold on the invisible hemisphere, since at the beginning and end of a cycle the sun is entirely free from spots.

Neglecting the extreme zones, where the disappearances may be more subject to error, there was obtained for each zone the number of spots which were seen in it for the first time and the number seen in it for the last time. The following result was noted:

As we go from east to west, crossing the visible hemisphere, there is an almost constant diminution in the number of spot appearances over a whole spot cycle and as nearly constant and even greater augmentation in the number of disappearances.

When we compare two symmetrical regions of the disk, the number of births found in one is generally smaller than the number of disappearances in the corresponding region on the other side of the central meridian.

If we were dealing only with numbers, the departures noted might be considered as resulting from a psychological cause. It is probable that there is in an observer a certain, perhaps unconscious, laziness which keeps him from recording new appearances and prolonging old spots unless absolutely necessary. It is always more agreeable to register a disappearance which simplifies work rather an appearance which augments it.

Thus, when a new small spot appears for the first time, there is a tendency to include it among those already noted rather than to regard it as an advance guard or germ of a new group. If the first impression is wrong, then there results an unjustified diminution of births in the visible hemisphere.

In a similar manner, if a small group approaches a more important group, either by expansion or derivation, there will be a tendency not to consider it separately and to cease counting it as soon as the separation between it and the larger group ceases to be distinct. We are thus led to credit fictitious disappearances to the visible hemisphere.

Both these considerations lead us to record more disappearances than births. But these errors in counting do not explain why the total area of spots is regularly found greater in the eastern half of the visible disk. Considering all of Mrs. Maunder's results we are led to think that the presence of the earth above the horizon of a place on the sun tends to make spots there disappear.

CHECK METHODS.

This result is in a way too beautiful. We had hoped to find only a small influence and we find one so decided that there is little room left for the other planets. Accordingly, search has been justly made for other proofs. We may, for instance, compare—

(1) Only the areas, in the east and west halves, of the groups of long life which have been completely followed across the disk. Here, again, without exception, for all symmetrical pairs of zones, the advantage remains with the eastern half of the disk.

(2) We may retain only the groups of long life seen in more than two successive rotations, neglecting the first and last appearances, keeping only the intermediate appearances. It is evident that in this way no appearance can be omitted or fictitious disappearance be registered. Despite these safeguards, the eastern portion still retains its advantage in the proportion of 19 parts in 100.

(3) We may substitute for the spot statistics those obtained from the protuberances observed on the east and west limbs and see if the protuberances show the same inequalities in activity as do the spots at the limb zones.

The protuberances, we have seen, follow more or less closely the solar cycle in their development. But the method of observation for the protuberances is quite different than for the spots. Mrs. Maunder found no sufficiently complete and homogeneous series of observations of the protuberances for the interval 1889 to 1901, which her spot statistics covered. The studies of Ricco at Catania, however, cover well the interval between the last two spot maxima. Diagrams made from this data show that from 1892 to 1900, during the decrease in spot numbers, the eastern limb had on the average more protuberances than the western limb. The opposite condition held from 1900 to 1904, but after the spot maximum was reached in 1905 the eastern limb again regained its ascendancy. On the average, the eastern limb maintained a superiority of 1 to 20, less constant and less marked than in the case of the spots, but in the same sense.

Deslandres has recently pointed out a circumstance which may render the protuberances more easily visible on the east than on the west border. The sun, which we have reason to believe is electrified at its surface, must by its rotation create a magnetic field. The very mobile protuberances would be disturbed by this field so as to be bent at their upper part in the direction of the rotation. An observer would then not be in an impartial position relative to the two limbs of the sun. He will see better the oncoming protuberances which would be bent toward him than the disappearing ones which would be bent away. This hypothesis seems to be confirmed by the deformations and velocities of the protuberances.

A similar explanation is not so easy in the case of the spots. In order that they may be more easily visible on the eastern than on the western limb, we may suppose that they are followed, but not preceded, in their general rotation by some kind of a cloud. Each spot would then have its cloud, allowing the spot to be seen as it approached but hid more and more as it departed.

This explanation is not very convincing. In order that the cloud have an appreciable effect upon a great spot it would have to be at quite an elevation, and it is difficult to see how it would escape observation at the border of the sun. Its influence would not be felt except toward the ends of the spot's transit, and we have seen that the inequalities are noted in the same sense in all pairs of symmetrical zones.

(4) There remains one more test which we must not neglect. We could not pretend that the earth alone has such an influence upon the sun. If it is effective, then the other planets must be; and there are apparently three, Jupiter, Mercury, and Venus, which should be even more effective. How can we assure ourselves in this matter?

RESEARCHES OF THE KEW OBSERVERS.

The problem had already been attacked long ago by De la Rue, Balfour Stewart, Benjamin Loewy, astronomers at the Kew Observatory. (Proc. Roy. Soc., p. 210, 1872.) As the observations never related to but a half of the sun at a time, it was considered necessary at the start to determine and try to eliminate the influence which the position of the observer on the earth might have. The two following conclusions resulted from the preliminary examination:

(*a*) Upon the hemisphere visible from the earth the mean area occupied by the spots increases as the distance on either side of the central meridian increases.

(*b*) The spotted surface on the average is greater on the western than on the eastern half of the visible disk.

The second conclusion of the Kew observers is at variance with that of the more recent investigators. However, the years examined in the two cases have no part in common. The data used by Mrs. Maunder was so much more homogeneous and abundant that her conclusions should have greater weight.

Having completed their first examination, the Kew observers considered how to correct their data for the position of the observer. They could then, for any planet whatever, P, compare the hemisphere turned toward the planet P with that turned away. Relative to the circle limiting these two hemispheres, any other planet, P', could have any possible position in its orbit. It seemed right to admit that, if the interval considered be long enough, the effect of P' would

be eliminated and the effect of P would become evident by comparing the conditions on the two hemispheres.

It was found thus that the spotted areas tend to increase opposite to Mercury and Venus. Jupiter, upon which the greatest hope was placed, gave no definite result.

The work of the Kew observers has been rather severely criticized. The interval used seems too short for assuring the proper compensations, and the gaps in the data are considerable. The choice of the material selected has not always seemed justified.

RESEARCHES OF SCHUSTER.

In a recent memoir (Proc. Roy. Soc. 85A, p. 309, 1911) A. Schuster considered it advisable again to take up this problem, using the Greenwich photographs for the years 1874 to 1909. He considered only the births of spots lasting over the interval between the plates of two successive days. He excluded, as more subject to error, those births which, seen from the earth, appeared at less than 30° of longitude from the eastern border. There remained 4,271 spots to consider.

For each planet P, the sun was divided into 12 equivalent vertical zones. The solar meridian passing through the planet P formed the boundary between the zones 6 and 7 on the hemisphere toward the planet and between 12 and 1 on the farther side. The number of spots seen for the first time in each zone was counted and used to form a plot having as abscissæ the zone numbers.

The results are rather irregular especially if—as Schuster did at first—we consider separately the spots counted when the earth is east or west of the central meridian. Of the three planets—Mercury, Jupiter, or Venus—each one seems to produce a minimum of spots where another may produce a maximum. If the above distinction is not made, the results seem more concordant. For all there is a minimum upon zone 3, that is when the planet is just rising, and a maximum on zone 8, which has already passed the meridian. This can be compared with the diurnal march of temperature on the earth due to the influence of the sun's heat. But there are other intermediate maxima and minima for which the three planets are in no ways in accord.

Schuster, however, considers that the similarity of march of the three curves for divisions 3 and 8 is sufficiently characteristic for rendering very probable the reality of a planetary influence.

This march is very different from that which had been found for the earth and much less definite. The effective activity of the earth is therefore apparently of another nature and relatively stronger, or it is only apparent and due to the situation of the observer.

The question was next taken up whether the distribution of spots in longitude did not become more unequal when the three planets considered, or two of them, were in conjunction for the same solar zone.   The plots were remade considering only the spots born when that condition was fulfilled.   No marked difference was evident.   It seems as if the number of spots appearing in a zone is greater only when one of the planets in the conjunction, or slightly past it, is Venus.   Schuster thinks that a planet may have merely an exciting action, effective only in putting into play a force already existing in the sun.   Accordingly, a second planet on conjunction might not have any additional effect.

RESEARCHES OF F. J. M. STRATTON.

Stratton (Monthly Notices, 72, p. 9, 1911) thought that it would be worth while to again take up this research, considering the disappearances as well as the appearances, and retaining only those which occur at less than 50 degrees from the solar meridian passing through the earth.   He considers only Jupiter and Venus, which seemed the most probable as having an influence on the spottedness.   The period used was the one of 36 years, 1874 to 1909, for which the photographs of the Greenwich Observatory furnished a complete series.

The surface of the sun was divided into 24 equal zones instead of the 12 which Schuster used.   The origin was the meridian passing through the planet at the moment of birth or disappearance of a spot.   The zones 0 to 6 corresponded to meridians which had already passed over the planet but which are now hid from it.   The zones 18 to 24 corresponded to meridians which are to transit but which are still out of sight.

He then constructed for each planet plots in which the abscissæ were the zone numbers and the ordinates—

(a) The number of spots seen for the first time in each zone.

(b) The number of spots seen for the first time in the northern part of each zone.

(c) The number of spots seen for the first time in the southern part of each zone.

(d) The number of ephemeral (that is, seen for one day only) spots seen in each zone.

(e) Total number of spots seen either for the first time or for one day only in each zone.

This gave five curves for each planet.   These were remade, using the spots seen for the last time instead of those seen for the first time; that is, disappearances instead of appearances.

The plots were very irregular. Generally there was no similarity in their contour, even for the same planet, between the two hemispheres; neither was there between the same homispheres for different planets. There is one single coincidence, perhaps, which seems not due to chance. There is a maximum of ephemeral spots noted in the zones the meridians of which either Jupiter or Venus had already passed three hours previously.

It is notable that for this interval of 36 years a terrestrial observer always notes in the central region of the sun more disappearances than appearances. The difference reaches 10 parts per 100. This agrees with what Mrs. Maunder found for the interval 1889 to 1901. For Jupiter and Venus the births seem more frequent when the planet is above than when under the horizon; that is, in the opposite sense from what Mrs. Maunder found for the earth. But the difference is very small and merits no physical explanation.

The relation between the east and west hemispheres of the sun, as seen from a planet, is for Venus in the opposite sense than is the case for the earth. In the case of Jupiter there is scarcely any difference, as the following table shows:

Spots seen on the hemisphere of the sun toward a planet.

	East half.	West half.
Jupiter	8,792	8,711
Earth	8,213	7,508
Venus	7,834	8,368

Another comparison may throw some light on the matter. When a planet is on a given side of the equator is the hemisphere on the same side as the planet especially favored with spots? The reply is contained in the following table:

Planet.	South, number of spots.		North, number of spots.	
	South.	North.	South.	North.
Jupiter	8,419	5,621	5,785	5,931
Earth	1,512	1,254	1,485	1,329
Venus	6,931	5,750	7,381	6,212

This table seems significant if only the left half is considered. But the preponderance in the southern hemisphere continues whether the planet is to the south or to the north. That is, in the interval considered, the southern hemisphere of the sun had habitually more spots. This may be due to causes within the sun and to no influences from the planets.

This simple comparison leads us to suspect that the concordances noted in the plots for the various planets may be due to causes within the sun.   There are two possible reasons for the inequalities in the plots:

(*a*) Any given zone relative to the planet can remain invisible from the earth for months.

(*b*) The epoch when a particular planetary zone may be favorably seen by a terrestrial observer may fall sometimes in the spot maximum phase, sometimes in the minimum phase.

The second perturbing effect is graver than the first.   The period of 36 years embraced by the Greenwich data is not sufficiently long to assure us that these two sources of error are eliminated.   The method should not be abandoned, but we must get more observations.

<div align="center">CONCLUSIONS.</div>

It would be presumptious to say that we have unveiled the mode in which the planets may react upon the sun, but we feel persuaded that some reaction exists and that it will not always elude us.   The sun may have within itself the reason for its period, but it does not keep to itself its rythmic action.   If it has not sufficient store of energy in the mutual attraction of its parts, in its rotation or in the active force of the plants, there remains a resource in the cosmic dust. Perhaps it is not the matter condensed into the shining stars but that which is scattered in impalpable particles throughout space which contributes more to the stability of the universe.

It seems to me that these views suggested by the study of the heavens help to keep us even in every-day life from discouragement and indifference.   The historian, whose attention is focused on salient events, may believe that the human race exists only for a few marked men.   The naturalist, accustomed to note the annihilation of the weak, cries willingly with the poet, " Le vent n'ecoute pas gemir la feuille morte " (The wind hears not the sigh of the lifeless leaf). But that is only apparently true.   The dead leaf, in its manner and measure, reacts on the wind.   Already religious moralists warn us that every act, no matter how small and weak, has a sovereign value when it is done in conformity with the eternal order.   And this conclusion will not surprise the geometrician, who is constrained to weigh all in an impartial balance and recognizes in the smallest corner of the universe an unlimited influence with regard to space and the future.

RECENT PROGRESS IN ASTROPHYSICS.

By C. G. Abbot.

[With 3 plates.]

According to the definition of the word by the late Prof. Newcomb in the last edition of the Encyclopædia Britannica, "Astrophysics is that branch of astronomical science which treats of the physical constitution of the heavenly bodies." Interpreting this definition in a manner somewhat narrower than that which is generally accepted in astronomical circles, Prof. Newcomb, in his article on astrophysics, mentioned the principal conclusions of the science to be that the heavenly bodies are composed of like matter with that which we find to make up our globe; that as a rule the incandescent heavenly bodies are mainly composed of gas, or of substances gaseous in their nature; and that the temperature of the great heavenly bodies is extremely high. He thus omitted from the province of astrophysics the study of the motions of the celestial objects and their parts by aid of the spectroscope, although this certainly has a bearing on the physical constitution of these objects. Information of fundamental importance in relation to the nature of the heavenly bodies and the evolution of the universe has resulted from investigations of the radial velocity of stars by the spectroscope; and this is supplemented and confirmed by observations with the telescope alone. Hence I shall not confine myself strictly in what follows to Prof. Newcomb's definition of astrophysics, but shall include the discussion of several subjects which have at least an astrophysical bearing, though not strictly, perhaps, astrophysical in themselves.

THE WAVE LENGTHS OF LIGHT.

All modern spectroscopic progress depends upon the exact knowledge of the wave lengths of the lines of absorption or emission of the chemical elements. Long ago it was discovered that sodium and its compounls, when heated to incandescense, gave out a yellow light, which when examined by the spectroscope, resolved itself into two lines of wave lengths 5,890 and 5,896 Ångström units. It was also found that when sodium vapor was interposed between a source of white light, like the electric arc, and the slit of the spectroscope, there would be found in the place of the bright yellow lines of sodium

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two dark lines of absorption, where light of the arc spectrum was taken away. Similarly, in the spectrum of iron, a great number of bright lines are found in the green; and if iron vapor is interposed between an electric arc light and the slit of the spectroscope, a great number of absorption lines will be found at the corresponding places. Also in the spectra of the sun and of many of the stars there occur dark lines corresponding exactly in place to the bright lines of the spectra of the chemical elements found upon the earth's surface. From these indications it is clear that these chemical elements exist as vapors in the substance of the sun and stars. The number of chemical elements in the sun and stars is so considerable and the number of their spectrum lines is so great, that the solar and stellar spectra are thronged with dark lines, so that it takes the most exact knowledge of the positions of the lines to insure for them a correct interpretation.

But in recent years a great deal more has been learned by the aid of the spectroscope in regard to the sun and stars than of their mere constitution, for it is found that although the spectrum lines occur almost exactly in the same position in the spectra of the heavenly bodies that they do in the spectra of the laboratory, yet there are slight and very significant deviations of position which are attributable to the motion of the heavenly bodies to or from the earth. For, just as in the whistle of a locomotive, there is a sharping or flatting of the pitch, depending upon whether the locomotive is coming toward the observer or going away from him, so in the light of the stars there is a displacement of the spectrum lines toward the violet or toward the red, according as the star is approaching toward or receding from the earth. One may go even farther, and say that there is a difference in the position of the spectrum lines of the sun according as we take the light from one edge of the sun or the other. For one edge is approaching the earth by virtue of the rotation of the sun while the other is receding. It is also shown that the position of the spectrum lines depends upon the pressure of the gases in which they are produced, so that it is possible to determine by exact measurements the pressures under which the gases lie in the sun and stars, although these are so extraordinarily remote that it takes light minutes or years to reach the earth from them. Finally, it has been shown by Zeeman that the form of the spectrum lines of the chemical elements differs according to whether the light is produced in a magnetic field or not. Accordingly it is possible to determine from measurements of the solar spectrum whether magnetic fields exist in the sun, and, if so, to what intensity they rise.

All these kinds of measurement, which depend upon extremely slight displacements of the spectrum lines, evidently require that great accuracy shall be obtained in the determinations of the positions

of these lines in the laboratory. When about the year 1895 Rowland completed his investigation of the spectrum of the sun and of the chemical elements, it was thought that the last word had been said upon this, and that no greater accuracy of positions of the spectrum lines was necessary, or indeed possible, than he had obtained. But in recent years it has been found necessary to go over the whole ground again, and to determine the positions of the lines of the chemical elements and the lines in the spectrum of the sun with a still greater accuracy than that of Rowland. This work has been taken up under the auspices of the International Solar Union, and is now approaching a satisfactory completion.

In the year 1893 a remarkable piece of work was carried out by Prof. Michelson (now of the University of Chicago) in the measurement of the wave length of light in terms of the standard meter of the International Bureau of Weights and Measures at Paris. Several of the spectrum lines were investigated, and among them the red line of cadmium, whose wave length as determined by Michelson is 6438.4722 Ångström units.[1] In pursuance of the investigations recently recommended by the International Solar Union, Messrs. Fabry and Perot remeasured the wave length of the cadmium line and found the value 6438.4696, which, it will be seen, differs by less than 3 parts in 6,000,000 from that obtained by Michelson. On this value of Fabry and Perot will rest the system of wave lengths adopted by the International Solar Union.

It had been determined at the meeting of the Union on Mount Wilson in 1910 that only wave lengths which are independently determined with satisfactory agreement by three observers with the most approved apparatus should be accepted as secondary wavelength standards. In pursuance of this action of the Solar Union, Messrs. Fabry and Buisson in France, Pfund at Baltimore, Eversheim and Burns in Germany, have been determining with the highest possible accuracy the wave lengths of certain lines in the spectra of iron and nickel, selected at nearly equal intervals of wave length. About 85 such lines have now been measured with satisfactory agreement in three or more independent investigations, and have been adopted by the International Solar Union as secondary standards of wave length. These lines cover the spectrum from a wave length 3370.789 Ångström units, which is far beyond the visible limit of the spectrum in the violet, to wave length 6750.163 Ångström units, which is near the limit of the visible red. It is expected that further investigations will carry the lists of secondary standards as far as wave length 2,000 in the ultra-violet, and perhaps as far as wave length 10,000 in the infrared. The astonishing accuracy of the results obtained may be inferred when it is said that the three inde-

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[1] The Ångström unit is one ten-billionth of a meter

pendent investigations generally agree to the seventh place of significant figures. Also St. John and Ware have investigated the consistency of the standards, each to each, by determining other wave lengths independently by interpolation from several different standards, and are of the opinion that adjustments in the seventh place of significant figures are hardly ever necessary, and will perhaps never exceed 0.002 Ångström units in any case. Investigations are now on foot by St. John and Ware, Goos, Burns, and others to determine a large number of tertiary standards of wave lengths intermediate between these secondary standards, and it is hoped that good agreement in regard to the tertiary standards will soon be obtained.

It is found necessary in this work to specify the strength of the electric current, the length of its arc, and the position of the slit of the spectroscope with respect to the arc in order to get satisfactory results. It now remains to go over the whole system of spectra of all the chemical elements and determine the positions of their lines with respect to these standard lines of iron, nickel, and barium which have been adopted, and further to go over the whole solar spectrum and to determine the position of its absorption lines with respect to these standards.

Although this will involve an enormous amount of careful work in photography of the spectrum and in the measurements of the results, a work which will be so exacting as to appear at times almost a drudgery to those who are engaged in it, yet like other good work it is almost beyond question that it will yield unexpected fruits of discovery in addition to those of investigations of the nature of the sun and of the stars for which it is primarily undertaken.

SOLAR PROBLEMS.

1. THE NATURE OF SUN SPOTS.

Soon after the invention of the telescope, Galileo, in the year 1610, observed spots on the sun. They continued to be observed by many persons, and in the middle of the nineteenth century it was found by Schwabe that the appearance of them was periodic. The average interval between successive maxima or minima of sun spots is 11 years, but individual periods range from 8 years to 15 years in length. The years from 1905 to 1910 were distinguished for large numbers of sun spots, and the years 1910 to the present time for very small numbers. We are now probably just at the beginning of a new sunspot maximum period, so that the report of spots being seen upon the surface of the sun need not surprise us. Sun spots, as seen in the telescope, consist of a dark central part called the umbra, and a less dark shading around it called the penumbra. The appearance of the sun when large spots are upon its surface is shown in the accompanying figure (pl. 1).
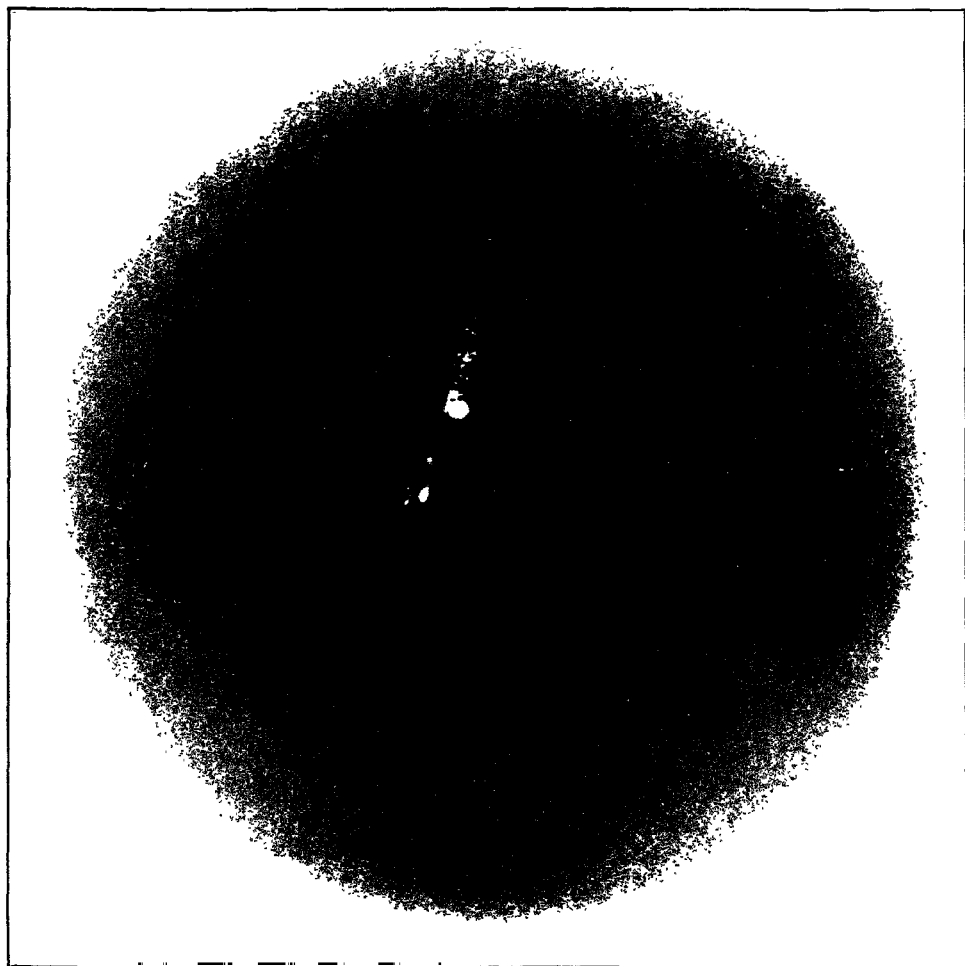
SOLAR PHOTOGRAPH SHOWING SUN SPOTS.

Taken from the Astrophysical Journal, volume 32, plate 1, figure 1, article of Slocum, page 24, 1910.

PLATE 2.

Smithsonian Report, 1913.—Abbot
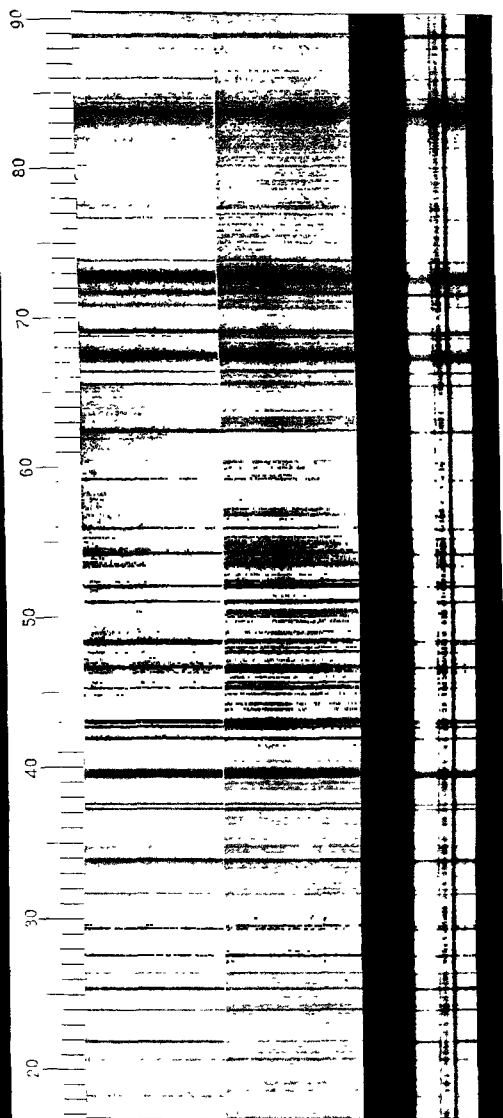
SUN-SPOT SPECTRUM MAP BY MOUNT WILSON SOLAR OBSERVATORY.

Taken from Abbot's "The Sun" (Copyright, 1911, D. Appleton & Co.), plate 17, page 210.

The nature of sun spots has long been a subject of investigation. In the last few years comparatively satisfactory conclusions have been drawn. It appears that sun spots are cooler than the surrounding surface of the sun. This is shown in several ways. In the first place, a delicate electrical thermometer, called the bolometer, in the hands of Langley and subsequent investigators, has shown a decreased temperature when exposed to the rays from sun spots, as compared with its temperature when exposed to the rays of the surface of the sun close by. In the second place, the spectrum of the sun spot is found to differ from the spectrum of the solar surface in the immediate neighborhood in certain very characteristic ways. This difference has been investigated by the Mount Wilson Solar Observatory. A photographic map of the sun-spot spectrum as compared with the spectrum of the sun's surface has been published by that observatory. The accompanying illustration (pl. 2) is taken from an interesting portion of such a spectrum map.

It shows in the first place that a large number of lines are found in the sun-spot spectrum which are either very indistinct, or not to be seen at all in the spectrum of the sun's surface. It shows in the second place that certain lines are broadened, or made double, in the spectrum of the sun spot as compared with the spectrum of the surroundings. In the third place, that some lines are weakened and some strengthened in sun spots, as compared with those of the surroundings. The cause of the numerous additional lines in the sun-spot spectrum has been found to be the presence of certain compound substances, such as calcium hydride, magnesium hydride, and certain oxides, as, for example, that of titanium. The cause of the different intensity of certain lines in the spectra of the spot and of the surroundings is shown by Hale, Adams, and Gale to be the decreased temperature of the sun spot. This conclusion they confirm, line for line, by noting the behavior of the lines of the corresponding chemical elements when observed at different temperatures, by the aid of the spectroscope, in the laboratory.

The doubling or widening of the lines of the sun-spot spectrum was found by Hale to be due to the presence in sun spots of a magnetic field. This observation depends on the discovery of Zeeman that the spectrum lines of the chemical elements, when produced in a strong magnetic field, are often doubled or trebled or made even more complex. The component lines, so produced, depend as regards their position, number, and the polarization of their light, upon the strength and direction of the magnetic field through which they are observed. The relation of magnetization to the polarization of the light was the feature of the matter which laid the subject of the widening of lines in sun spots open to Hale's investigation. By the use of proper apparatus for the polarizing and analyzing of light,

he was able to remove or alter the individual components of the spectrum lines in a manner adapted to show the magnetic field existing in the sun spots where the light was produced. This most interesting discovery he has now pushed still further, and has examined the magnetic field of the whole surface of the sun. He finds that there exists upon the sun a magnetic field similar in many of its characteristics to that which exists in the earth, although the intensity of the field is so extremely slight that the shifts or alterations of spectrum lines caused by it are almost beyond the possibility of disclosure.

Recently it was shown by Evershed that in the penumbras or darkened edges of sun spots, there are found shiftings of the spectrum lines which show that the vapors are moving outward from the center of the spot, or umbra, toward the outlying parts of the penumbra. Later investigation shows that this outflow of the gases from the umbra toward the outer part of the penumbra is accompanied by a motion of rotation also around the umbra, so that the motion resolves itself into a whirling of these vapors or gases similar to that which is found in a waterspout. This has a very important bearing on the explanation of the magnetic field in sun spots discovered by Hale, for it was shown by Rowland many years ago that an electric charge in motion has the property of an electric current of producing a magnetic field. Thus if there are in sun spots materials under dissimilar electric conditions, and these materials be whirled as in a waterspout, they must necessarily produce a magnetic field. St. John, of the Mount Wilson Solar Observatory, has made a thorough investigation of the motions of the vapors in the neighborhood of sun spots, using the spectrum lines of many of the chemical elements. He finds that the displacements of the spectrum lines of iron and some other well-known metals indicates a motion away from the umbra. The motion, on the other hand, of magnesium and hydrogen and some other of the lighter chemical elements is toward the umbra. Is was also shown some years ago in a photograph by St. John that hydrogen gas is sometimes sucked into the center of a sun spot.

All these various lines of evidence indicate that a sun spot is a whirl in the gases of the outer part of the sun, analagous to a waterspout, and that this whirl comes from within outward. Associated with the whirl there is produced a magnetic field, and associated with the outward motion of the materials a decrease of pressure. The decreased pressure of the gases causes their expansion and consequent cooling, so that the coolness of the sun spot is thereby explained. As the gases spread out at the surface of the sun, the lighter gases—hydrogen and others—which are found in the outermost solar layers, are sucked into the partial vacuum at the center of the whirl.

2. SOUNDING THE SOLAR DEPTHS.

St. John's investigations of radial motion in the neighborhood of sun spots have led him to further very interesting results. For it appears that if one takes the various lines of iron as found in the
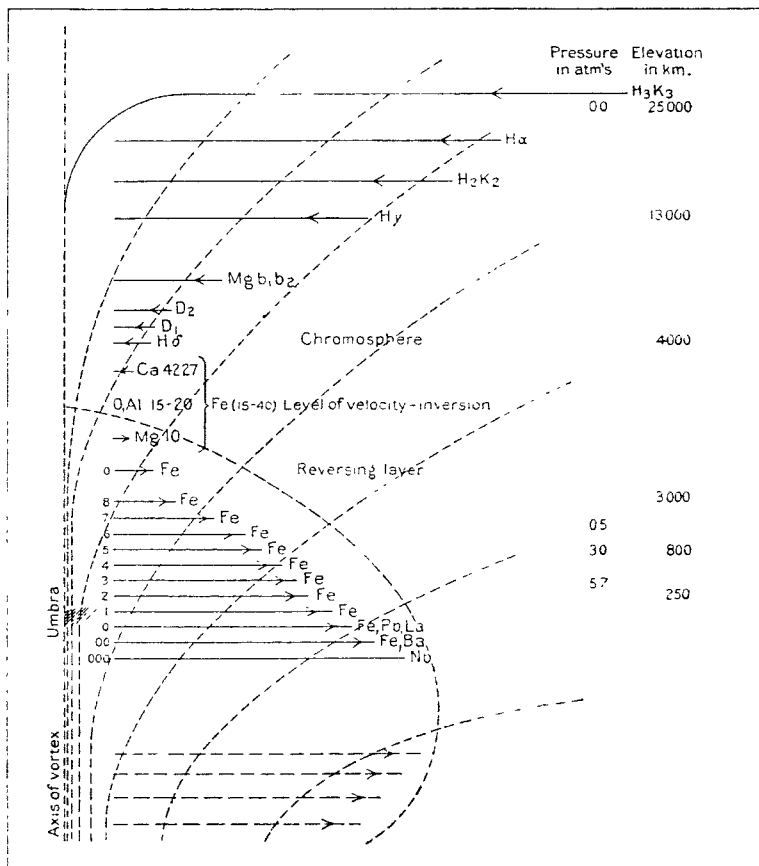
FIG. 1.—Vertical section of reversing layer and chromosphere, showing distribution of radial velocities of sun spots.

The lengths of solid lines are proportional to radial displacements of the corresponding Fraunhofer lines. Arrows indicate direction of flow. The rounded head of the cyclonic disturbance is suggested by the broken-line curve enveloping the outward velocities. Broken lines with arrows refer to possible velocities below the accessible levels. Lines of force of the magnetic field are indicated in the usual way.—From Report on Mount Wilson Solar Observatory, by George E. Hale, Twelfth Year Book Carnegie Institution of Washington, 1913.

sun's spectrum, classifying them according to their faintness after the manner of Rowland, the fainter lines show greater displacements and thereby more rapid outflowing in the sun-spot whirls than do the brighter ones. In fact, the brightest iron lines show less than a

fourth as great displacements as do the fainter ones. Now, it appears from various lines of reasoning that the fainter lines should be the ones that are formed at the greatest depths, so that St. John is able to arrange the iron spectrum with reference to faintness and with reference to velocity of outflow in sun spots in a series which very probably indicates a progressive depth of sounding below the surface of the sun. Then corresponding to this iron scale, if he takes the lines of the other chemical elements, comparing them line by line as regards velocity of outflow with the velocity shown by his iron scale, he may arrange all the chemical elements in terms of the iron scale, in the order of their depths of occurrence below the sun's surface.

In this way he finds, as is indeed indicated by other lines of research, that the heavy chemical elements will lie the lowest, and vice versa. Corresponding to this arrangement it is natural to find that the lines of calcium, sodium, magnesium, and hydrogen indicate a flow of greater and greater velocity in the opposite direction from those of iron, so that these elements are arranged above the uppermost level of the iron lines in a progress outward from the general solar surface. Thus, as shown in figure 1, we may have the arrangement of the vapors as they exist in the sun, from the hydrogen at the highest level down to the elements like lead, lanthanum, barium, at relatively low levels. Such elements as uranium (and radium, if it exists in the sun) are so very high in atomic weight that they lie very deep down in the sun and do not give solar-spectrum lines at all, so that we shall probably not obtain direct proof of the existence of radium in the sun on account of the low level at which it must lie if present there. We have, to be sure, long known of the existence in the sun of helium, which is a product of the disintegration of radium. This may, perhaps, indicate that the parent substance, radium, is also present in the sun, but of this there is no certainty.

3. MEASUREMENTS OF SOLAR RADIATION

In the Smithsonian Report for 1912 the writer gave an illustrated account of the investigations of solar radiation by the Astrophysical Observatory of the Smithsonian Institution. In July, 1913, the results of this long investigation were published with details in volume 3 of the Annals of the Astrophysical Observatory. The most important conclusions are as follows:

1. The mean value of the solar constant of radiation for the epoch 1905–1912 is 1.932 calories per square centimeter per minute.

2. An increase of 0.07 calory per square centimeter per minute in the "solar constant" accompanies an increase of 100 sun-spot numbers.

3. An irregular variation frequently ranging over 0.07 calory per square centimeter per minute within an interval of 10 days is

established by numerous nearly simultaneous measurements at Mount Wilson, Cal., and Bassour, Algeria.

4. Indications of two wholly independent kinds incline us to think that these variations of solar radiation are caused within the sun, and not by interposing meteoric or other matter.

STELLAR PROBLEMS.

I. THE DISTANCES OF THE STARS.

The actual distances of several hundred of the stars can be said to be known within moderate limits of accuracy. Various methods are used for determining the distances of the stars, but they generally depend upon the fact that the earth, by reason of its revolution about the sun, occupies places separated by 186,000,000 miles at intervals six months apart. This corresponds to the surveyor's base line, and allows us to triangulate for the distances of the stars. Another method of estimating the stellar distances may be based upon the fact that the solar system is approaching the constellation Hercules at the rate of about 20 kilometers (12 miles) per second, so that the position occupied by the earth in space to-day is different from that which will be occupied to-morrow by reason of the motion of the solar system, but this method involves assumptions in regard to the motions peculiar to the stars observed.

It is customary to express the distances of the stars in light-years, for the distances of the stars, if given in kilometers or miles, or even in terms of the radius of the earth's orbit, are so enormous as to require many figures. Light, however, traveling at the rate of 186,000 miles per second, in the course of a year travels about 6,000,000,-000,000 miles. In terms of this unit the nearest star is at a distance of four and a half light-years. The stellar distances are considered up to such enormous quantities as a thousand or more light-years. It is also customary to speak of the parallaxes of stars. By this is meant the angle which the radius of the earth's orbit would subtend if viewed most favorably from the star in question. The parallaxes of the stars range from about one second of arc (1″) downward. The following table shows the relation between miles, light-years, and parallaxes of stars:

Star.	α Centauri.	Procyon.	Altair.	Castor.	Arcturus.	Antares.
Parallax....	0.75″	0.33″	0.23″	0.10″	0.066″	0.02″
Light-years.	4.5	10.0	14.5	33.3	50.0	166.7
Miles [1]......	[1] 27,000,000	[1] 60,000,000	[1] 87,000,000	[1] 200,000,000	[1] 300,000,000	[1] 1,000,000,000

[1] 000,000 omitted.

The first successful measurements on stellar parallaxes were made by Struve at Dorpat on the star Vega in the years 1835 to 1838, and

by Bessel on the star 61 Cygni, 1837 to 1840. Bessel's result was 0.35″. This value is in close accord with recent measurements. It was a great feat to measure such a small angle as this. In modern practice the efforts to measure parallaxes absolutely have practically been discontinued, for it is found that the very faint stars are so immensely distant from us as hardly to be displaced at all in their apparent positions by the motion of the earth in its orbit. Hence, for stars which are near enough to be observed for parallax it suffices to compare their positions with respect to the faint stars in their neighborhoods at two epochs separated from one another by six months.

Many of the parallax determinations of great weight have been made by use of the heliometer, which is a telescope with its objective lens cut in half, with the two parts movable with respect to one another by a fine screw. With this instrument the images of two celestial objects, one formed by one-half of the lens and the other by the other may be brought into coincidence by shifting the two parts of the lens with respect to one another, and the scale of the instrument gives thereby an indication of the angular distance between the two objects in the heavens. Thus the relative positions of the stars may be observed for parallax purposes.

Stellar parallax measurements by means of the heliometer have been the main work of the Astronomical Observatory of Yale University. A volume of the Transactions of the Observatory has been issued recently containing the results. The parallaxes of 195 stars have been ascertained with an average probable error of 0.015″. The stars investigated at Yale naturally do not include stars visible only in the southern hemisphere. The parallaxes of some of the southern stars have been observed with the heliometer from the Observatory of the Cape of Good Hope. Of the parallaxes determined at Yale the largest pertaining to a bright star is 0.33″ for the star Procyon, whose magnitude is 0.6, and which has a proper motion in the sky of 1.23″ per century.[1] According to the little table just given it will be seen that this corresponds to a distance of 10 light-years. The largest parallax found for any star by the

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[1] The stars have long been arranged with respect to their brightness, by "magnitudes." A number of the brightest stars in the heavens are regarded as of the first magnitude. The Polar Star is of the second magnitude, and the brightness of the faintest of the six readily visible stars in the constellation Pleiades is 4.4 magnitudes. An increase of five magnitudes corresponds to a decrease of a hundredfold in the brightness of the stars. It was found when the measured distances of the stars were arranged in the order of the magnitudes of the stars observed that the brighter stars were on the whole nearer to us than the fainter ones.

The "proper motion" of a star is ordinarily given as the angle through which the star moves in a century in the heavens, after allowances are made for all effects of nutation, precession, aberration, etc., but not for the motion of the solar system toward the constellation Hercules. Proper motion therefore includes the star's real motion in space with reference to the whole system of stars and, in addition, the star's apparent motion, really due to the motion of the solar system toward the constellation Hercules. Proper motions tend of course to diminish the greater the distances of the stars considered.

observations at Yale was 0.39″ for the faint star known as Lalande 21185. This star is invisible to the eye, being of magnitude 7.3 and has a proper motion of 4.77″ per century.

Another method of parallax investigation which has been developed in recent years to a high state of perfection is that by photography. If a photograph of a celestial region containing the star whose parallax is to be determined is made in the earlier part of the night at one epoch, and again in the latter part of the night at an epoch six months later, the position of the parallax star will in general be found to be changed with respect to the mean position of all the fainter stars in its neighborhood. After clearing the apparent motions for the known proper motions of the stars in question, a residual effect will be left, due to the fact that the parallax star is in general nearer than the fainter stars in the background. In a method proposed by Kapteyn the photography was done in the following manner: A plate was exposed at a certain epoch, then kept without developing for six months. exposed again in a slightly different position, and then kept still another six months, and finally exposed a third time before developing. Thus three series of images of all the stars would be found upon the plate. of which two would be taken with the earth in one part of its orbit and the other with the earth at the opposite part. Recently Prof. Schlesinger, formerly of the Yerkes Observatory, now director of the Allegheny Observatory, has used the photographic method with the great Yerkes refractor, and has obtained parallaxes for about 25 stars of a very high order of accuracy. Prof. H. N. Russell, of Princeton, also has obtained excellent results by this method for 52 stars observed by himself and Hinks at Cambridge, England. These observers did not leave the plates undeveloped for a year or 18 months, according to the method proposed by Kapteyn, but preferred to take separate plates at the different epochs. This parallax work by photography is becoming extremely well thought of by astronomers, and is engaging more and more the efforts of those who have large refracting telescopes available for this purpose.

It is found, as would be expected, that in general the brightest stars are nearer the earth, and the stars whose proper motions are largest are also nearer the earth. Prof. Kapteyn published, in 1902, a formula connecting the quantities parallax, stellar magnitude, and proper motion. This is found to agree pretty well with more recent work. Prof. Lewis Boss, in his interesting discussion of the great Preliminary General Catalogue of positions and proper motions of stars, recently published by the Carnegie Institution, has also derived a formula connecting the proper motion and the parallax for stars of the 5.3 magnitude.

The positions of the stars in the heavens change slightly from year to year, owing to two causes: First, the motion of the solar system as a whole in the direction toward the constellation Hercules; second, the individual motions peculiar to stars themselves. The first-mentioned component of proper motion increases directly as the stellar distance descreases. Stellar parallax observers, being overwhelmed by the enormous number of the stars, were obliged to choose from them a small list for observation. It was natural to select stars of large proper motion for such a purpose, since these would probably represent the class nearest to the earth. Hence if we take, for instance, from the list of stars whose parallax has been determined a group whose mean parallax is 0.1″, the mean of their proper motions exceeds the mean proper motion, which would be found for all the stars whose parallax is 0.1″, if all those stars had been investigated. Hence it must occur that, as the distances of more and more of the stars become known, our estimated value for the mean distance, corresponding to stars of a given brightness or a given proper motion must diminish.

2. MOTIONS OF THE STARS.

Within the last few years great pieces of statistical investigation in relation to the stars have been published which are of the highest value for the progress of our knowledge of the universe. Americans should be particularly proud of several of these investigations.

The first is by the Harvard College Observatory, under the direction of Prof. E. C. Pickering. Volume 50 of its annals, containing the Revised Harvard Photometry, gives a catalogue of the positions, photometric magnitudes, and spectra of 9,110 stars, mainly of the 6.5 magnitude and brighter, covering both the northern and southern hemisphere. A still more extensive work of a similar kind, to be called the Revised Draper Catalogue, which will include data for probably 200,000 stars, is now in course of preparation at the Harvard College Observatory and may be expected to be finished within a short time, thanks to Prof. Pickering's great care in the arrangement of the work.

The second great work to which I refer is entitled " Preliminary General Catalogue of 6,188 stars for the epoch 1900. Prepared at the Dudley Observatory, Albany, N. Y., by Lewis Boss and published by the Department of Meridian Astrometry of the Carnegie Institution of Washington, 1910." Prof. Boss says: " The general catalogue of 6,188 stars herein contained is the result of an attempt to deduce for these stars the most exact positions and motions that are readily attainable from the means at command." In compiling it he has compared about 80 star catalogues, from the catalogue of Bradley, dated 1755, to modern catalogues of the period 1900. From

these he has deduced the most probable positions in right ascension and declination of the stars, and the proper motions of the stars as indicated by the observations of them at long separated epochs. The result obtained with regard to proper motion have led him to a most interesting series of papers, some conclusions of which will be referred to in what follows:

The third great piece of work to which I have referred is not yet published in extenso. but has been published in part. It exists in maunscript, and the principal conclusions to be immediately derived from it have already been published in a series of interesting papers by Prof. W. W. Campbell. director of the Lick Observatory.

It is now 16 years since Director Campbell described the Mills spectrograph of the Lick Observatory. This fine instrument, re-modeled in 1902, has been unremittingly used by him until the present time. A companion Mills spectrograph was installed under Director Campbell's direction in Chile in the year 1903, and this also has been diligently employed by successive observers sent down from the Lick Observatory.

It was Director Campbell's intention in this long campaign to observe the spectra of all stars brighter than the fifth magnitude, in both the northern and southern hemispheres, in a manner adapted to determine accurately the motion of each of these stars in the line of sight; that is to say, in a direction toward or from the earth. This motion is also termed radial velocity. The time of exposure necessary for photographing a single spectrum ranges from a few minutes up to several hours, according to the brightness of the star and the quality of the atmospheric conditions. It is necessary in such a campaign as that which the Lick Observatory has been making to observe each of the stars several times in order to confirm the velocity found or to detect the presence of variability of velocity, such as often leads to the most interesting results. The Lick Observatories in California and Chile have observed between 1,000 and 2,000 stars for radial velocity, and these, with a considerable number of others observed by other observatories, made up a list exceeding 1,700 in number, which was discussed by Director Campbell in a series of papers in the year 1911.

About one-fourth of the stars observed were found to be spectroscopic binaries. That is to say, although they appeared to be single points of light to the telescope, yet certain peculiarities in the displacements of their spectrum lines from time to time indicated that each of the apparent points of light embraced a system of celestial objects comparable in some respects with the solar system. This similarity, however, does not extend to details, for the objects included in a spectroscopic binary, or multiple star, are each usually hot enough to give light by itself, and in general are objects of more

approximately equal size than the sun and the planets. The motions of a considerable number of these spectroscopic binaries have been investigated by mathematicians, and the orbits of the motions have been determined, but there still remains a large number of them for which this information is not yet available. These latter objects were rejected from Prof. Campbell's general discussion of the stellar motions on account of the indefiniteness which must attend their motions for a time. There are besides a considerable number of stars whose spectra are so vague and difficult to measure that the results from them are uncertain. Accordingly, there remained available for his investigation only about 1,200 objects.

The first investigation relates to the motion of the solar system in space. As in a forest walk the trees in front seem to separate as we approach and those behind to come together as we recede, so the stars to the telescopic observer would appear to crowd toward the point of the sky from which we are receding and to separate from that point of the sky toward which we are approaching, if the sun with the planets is in motion in the heavens with respect to the positions of the stars. Such tendencies were noted by Sir William Herschel in 1783, from a consideration of the proper motions of 13 stars, all then available. He found that the solar system was traveling approximately toward the star λ Hercules, in right ascension 262°, declination, +26°.

The information found by the spectroscope relates to motion at right angles to that which is observed by the telescope, so that while the telescopic observer would find the stars precisely in the solar apex to have no component of motion caused by their relations to the solar system, the spectroscopic observer would find these stars to be approaching the earth with the maximum velocity, while those at the opposite point would be receding from the earth with the same velocity. The telescopic observer, looking at right angles to the line of motion of the solar system, would see the stars at the maximum velocity, whereas the spectroscopic observer, looking in the same direction, would find no radial velocity at all caused by the solar motion.

Director Campbell's general solution for the solar motion derived from all the stars investigated, 1,193 in number, gave the following values: Apex at right ascension, 268°.5, declination +25°.1, and velocity 19.5 kilometers per second.

In Prof. Lewis Boss's discussion of the proper motions of 6,188 stars, he also has derived the position of the apex toward which the solar system is approaching. He finds it in right ascension 270°.52, declination +34°.28, and he finds that for stars situated at 90° from the apex, which of course, will show the greatest apparent velocity of recession from the apex, the mean rate of apparent mo-

tion is 3.85″ per year. This is called the mean solar parallactic motion for the star group. Now, of course, the parallactic motions of the stars depend upon their distances from the earth, and naturally will be less for the fainter stars than for the brighter ones, since the fainter ones are situated at the greatest distances.

The mean magnitude of all the stars investigated by Boss was 5.7, but he selects 559 stars having large proper motions whose average magnitude was 5.3 and for which the mean solar parallactic motion was 21.58″. Prof. Boss then goes on to compare the magnitude and parallaxes of 130 stars whose parallaxes had been measured, and thereby obtains a formula connecting the parallax and proper motion for stars of the magnitude 5.3. He thus has a measure of the distance of the stars of large proper motion which he is considering, and from this he finds that the velocity of the solar system, in its motion toward the constellation Hercules, is 24.5 kilometers (15 miles) per second. Readers will note that this value is derived quite independently from that of Prof. Campbell, and that it is about 25 per cent larger than his. But from the considerations above mentioned (under the caption " Distances of the stars ") probably a reduction of the estimated distances corresponding to given proper motions will be brought about as more determinations of stellar distances become available. Thus Prof. Boss's estimate will be brought down toward that of Prof. Campbell.

It is found that the fainter stars are on the whole at greater distances from the sun than the brighter ones, so that the star list of Boss relates on the average to a system of stars at a greater distance from the observer than the star list of Campbell. A reason has already been assigned for supposing Boss's value of the solar motion too high. It may be on the other hand that the sun's motion is to some extent shared by the stars which are its more immediate neighbors, so that its velocity with respect to them is smaller than with respect to the stars which are more remote.

Prof. Campbell has adopted in his later discussions the round numbers 270° right ascension and 30° declination for the position of the solar apex. and the velocity of 19.5 kilometers as the rate of its motion toward this apex.

With these quantities determined, it is possible to take from the observed radial velocity of each star a component which depends upon the motion of the sun, and thus to leave to each star its own individual motion with respect to the earth, as the earth would be if fixed in space with reference to the whole system of stars considered. As the sun moves at the rate of 19.5 kilometers per second in a certain direction. so for each of the other stars investigated, there should be a certain velocity and direction of motion. The stars have been classified at the Harvard College Observatory under the direc-

tion of Prof. E. C. Pickering, with regard to the nature of their spectrum. The principal groups of the Harvard classification are designated by the letters B, A, F, G, K, M. The peculiarities of these types of spectra are indicated in the accompanying plate 3. We see the progressive greater complexity of the spectra from type to type. Campbell points out the very interesting fact that the more complex the star spectrum, the greater the velocity of the star in space, with regard to a point so fixed that the algebraic sum of the velocities of all the stars with respect to it is 0. The same conclusion is derived independently by Boss from a consideration, not of radial motions, but of thwart motions of the stars. The results of Campbell and Boss are compared in the following table. We assume for Boss's results as for Campbell's that the velocity of the solar system toward its apex of motion is 19.5 kilometers per second, thus the angular motion observed by the telescope may be converted into its linear equivalent. Unfortunately the grouping of stars by the two observers is different as regards the subclasses of the Harvard classification.

Campbell.			Boss.		
Classes.	Number of stars.	Component of peculiar velocity (km. per second).	Classes.	Number of stars.	Component of peculiar velocity (km. per second).
B–B5....	[1] 312	6.2	Oe5–B5..	490	6.4
B8–B9...	90	6.7			
A........	172	10.5	B8–A4...	1,647	9.9
F........	180	14.4	A5–F5...	656	15.8
G........	118	15.9	G........	444	18.1
K........	346	16.8	K........	1,227	14.7
M........	71	17.1	M.......	222	16.7
	1,289			4,686	

[1] For 132 of these stars the radial velocity is estimated.

The reader must note that the results, both of Boss and of Campbell, relate only to a certain component of the motion of the stars. In the case of Boss it is derived from that component of the proper motion, which is at right angles to the solar pathway; and in that of Campbell it is that component of the radial motion which is in the plane of the star and the solar pathway and is at right angles to the solar motion. If it is assumed that the stars have no preference for motion in one direction rather than another and that they are well distributed over the whole celestial sphere it follows that the values above given from both observers are but half the average velocity of the group of stars, considering their motions in the real directions which they have in space, and not merely the components of motion found by Boss and Campbell. Thus we find for stars of group G,

PLATE 3.

B   ε Orionis.

A   α Can. Maj

F   α Carinæ

F₅   α Can. Min.

G   α Aurigæ.

K   α Bootis.

Ma   α Orionis.
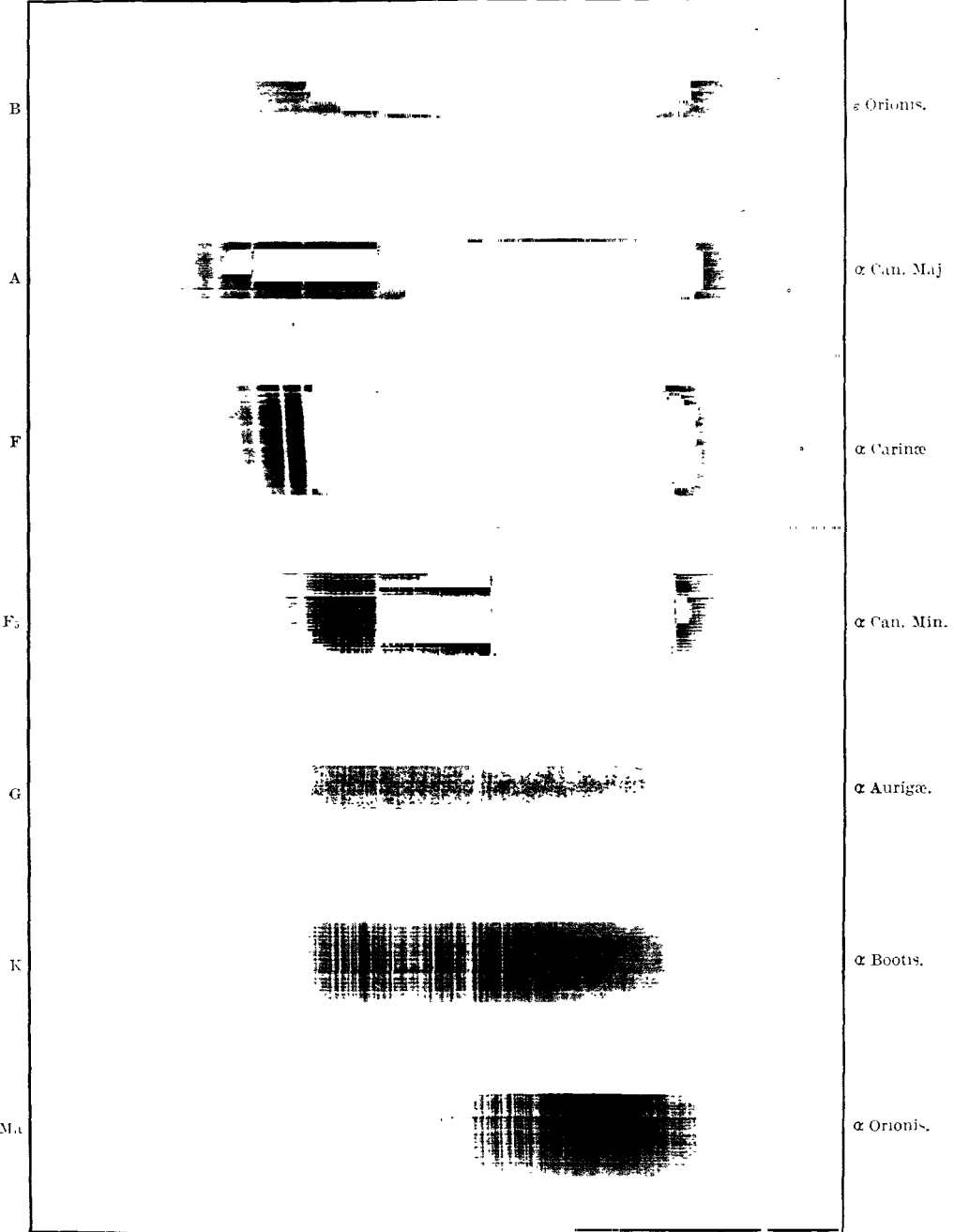
TYPICAL STELLAR SPECTRA.

From Annals Harvard College Observatory volume 64, No. 4, plate 1

to which our sun belongs, an average velocity of 32 or more kilometers per second, which is considerably greater than 19.5, which is assigned to our sun.

The Milky Way, composed as it is of a vast number of stars, has long been a circle of reference in the heavens for the discussion of the distribution of the stars. Not only are the individual stars crowded more closely in the Milky Way than elsewhere, but the crowding is different with different spectral types. Thus Prof. Pickering pointed out in his discussion of Harvard Revised Photometry that the stars of the early types, type B especially, were to be found preponderatingly in the neighborhood of the Milky Way. This tendency of the stars to distribute themselves differently with respect to the Milky Way has been summarized by Prof. Boss in the following tables, in which he gives the numbers of stars of different spectral types to be found in zones at different distances from the center of the Milky Way, and also the numbers of stars of the different types which occur in equal areas in these zones, assuming for the zone +10 to —10° a number of 100. We see that the stars of the so-called "later types" G K M are nearly uniformly distributed over the heavens, but that the stars of the "early types," especially B, are very unequally distributed, and crowd more and more toward the Milky Way.

ENUMERATION OF TYPES IN GALACTIC ZONES.

Zone.	Limits.	B	A	F	G	K	M
I	+10 to −10	237	422	142	103	237	33
II	±10 to ±30	105	310	104	63	205	34
III	±30 to ±50	14	170	89	66	155	31
IV	±50 to ±70	5	100	51	30	102	24
V	±70 to ±90	2	32	13	12	32	5

RELATIVE AREAL DENSITIES IN PERCENTAGES.

Zone.	Limits.	B	A	F	GKM
I	+10 to −10	100	100	100	100
II	±10 to ±30	47	78	78	87
III	±30 to ±50	7	53	82	84
IV	±50 to ±70	5	47	72	84
V	±70 to ±90	5	44	53	76

In several respects the stars of class B are very remarkable. Dr. Campbell has stated that in a space concentric with the sun, which must contain hundreds of stars of other spectral classes, there would probably not be a single one of class B. Thus, B stars are, on the whole, excessively remote. In the second place, they seem to be very bright stars, for, as Prof. Pickering states, a count of the class B

stars indicates that of the bright, visible stars one out of four belongs to this class, while of the stars of the sixth magnitude there is only 1 out of 20, and that few, if any, would be found fainter than the seventh or eighth magnitude.

It has been strongly intimated by such men as Kapteyn, Campbell, and Boss that the order of spectra B, A, F, G, K, M indicates substantially the order of development of the stars in time, so that the stars of class B may be regarded as the younger stars, and those of classes A, F, G, K, and M, successively, older and older.   Prof. Boss goes so far as to say: " There can scarcely be a doubt that the same stars that are now seen of the spectral type A were in past ages of the spectral type B, and then at a mean velocity of approximately only two-thirds or three-fourths that which they have at present.   It seems equally probable that A stars of the present will eventually become stars of the second[1] type in the future, and along with that physical development will acquire an increase of mean velocity about 50 per cent greater than that those stars now have.   This fundamental fact of acceleration in the means of the stellar motions must have a vital bearing on questions of stellar development."

It is known that the spectrum of the general surface of the sun, which is like that of stars of class G, goes over into the spectrum of a sun spot, which is like that of stars of class K, by a mere lowering of temperature.   It is also known of all bodies with which we are familiar upon the earth, that when, as time passes, they lose energy by radiation they cool.   Accordingly it seems probable that stars of class G will at length reach the condition of class K by the mere cooling incidental to the continuation of their radiation to space through long periods of time.   The gradual progress in form of spectrum from class B to class M, the gradual progress in velocity of motion from class B to class M, the gradual progress in distribution in space from class B to class M, and other lines of gradual progress which could be named, all seem to show that the arrangement of the stars according to this classification corresponds to the march of a fundamental progress in nature.   That this progress is in point of time from stars of simpler spectrum to those of the more complex, and not the opposite, is indicated by the consideration with regard to the sun-spot spectrum which I have just cited.

In contemplation of these various facts Prof. Campbell has remarked as follows:

The close relationship of the class B stars to the Milky Way, their low radial and tangential velocities, the apparent absence of class B stars in both near space and distant space, a clustering of many of these stars in apparently related groups—for example, in the Orion region—lead us to believe that the present class B stars assumed stellar form in regions relatively near their

[1] Of Secchi's classification, in which B to F types are I, G to K are II, and M is III.

present positions. They may have originated from comparatively few great separate collections of matter in or near the plane of the Milky Way. The variety of motions which we observe in the stars in one of these apparent groups might, perhaps, have originated from the influence of the passing of many individual stars through the immense volume of space occupied by the group. The absence of class B stars in our vicinity may indicate primeval vacancy in this region, or the development of the stars in this region to an effective age beyond that corresponding to the class B spectrum.

Kapteyn has said:

As the younger the stars are the smaller are their internal motions, it follows at on￼ that from whatever matter our youngest stars—the helium stars[1]— may ha￼ been evolved, that matter must have in all probability still smaller internal motion. Let us call this matter primordial matter. As the internal velocity of the helium stars is already so very small, we come to the conclusion that primordial matter must practically have hardly any other motion than the motion of the cloud to which it belongs.

The statements quoted above, and many others which might be quoted from astronomical literature, lead us to the conclusion that their writers assume the following evolution of the universe, beginning from the nebula, and proceeding with passing time to the stages of the classes B, A, F, G, K, M in spectra. Originally the matter had very low velocity in space, and as the stars were formed and grew in age their velocity became greater and greater. Whatever the drift which the original primordial matter may have had, the formation of the stars and the gravitation which they mutually exert, together with their increasing velocity in space, tended to alter the motions of the stars from a slow drift in some particular direction to a much more rapid progress of individual stars in every conceivable direction. This motion naturally took the stars of the later types farther and farther from the original seat of the primordial matter, so that now, although we find the class B stars still mainly confined to the neighborhood of the Milky Way, yet for other types of stars the dispersion has gone farther and farther. For stars similar in constitution to our sun, and naturally of the same order of age as the sun, the circumstances of the wandering have naturally been much the same, so that we find the stars of approximately the spectral class of our sun to be, on the whole, in the less remote parts of space. When, however, we consider the stars of most advanced type, of spectral class M, whose wanderings have continued for the most untold ages, we find these stars as a class in the more remote parts of the universe.

Although this speculation is supported by a good many facts of observation yet it is only fair to state that there are astronomers of very high eminence who consider either that the time is not ripe for such speculations, or that the evidence may equally well be

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[1] Class B.

arranged to suit other conclusions.   If we assume the line of speculation stated above we must be interested in the following statement of Prof. Kapteyn:

There is another problem involved in our observations which might seem to be of no less importance than the one just now considered.   How have we to explain the fact that the internal velocity of the stars increases with age?   The astronomer who, in the study of the motion of the heavenly bodies, has found hardly a trace of any other force than gravitation, will naturally turn to gravitation for such an explanation; and it really seems a necessity that under the influence of their mutual gravitation, bodies which at the outset have little or no relative motion must get such a motion. which, up to a certain limit at least. will increase with time.   Thus far there is no great difficulty.   But now let us look further back in time, back to the time in which the stars had not yet been formed, in which matter was still in its primordial state.   If it be true that mutual attraction of the stars has generated such an enormous amount of internal motion in the time needed by the stars for their evolution from helium to second or third type stars, how have we to explain the fact that we find that same matter nearly at rest at the first stage of stellar life?   That in the prehelium ages gravitation had produced hardly any motion?   He who believes in a creation of matter at some finitely remote epoch may find no difficulty in the question, but to him who does not, there is something astonishing to see matter behave as if there were no gravitation.   What may be the explanation?   Is there really no gravitation in primordial matter, or is there another force exactly counterbalancing its effects?

I have no solution to offer.   I simply wish to point out that here is a great problem, which in my opinion deserves the attention of the physicist no less than that of the astronomer.
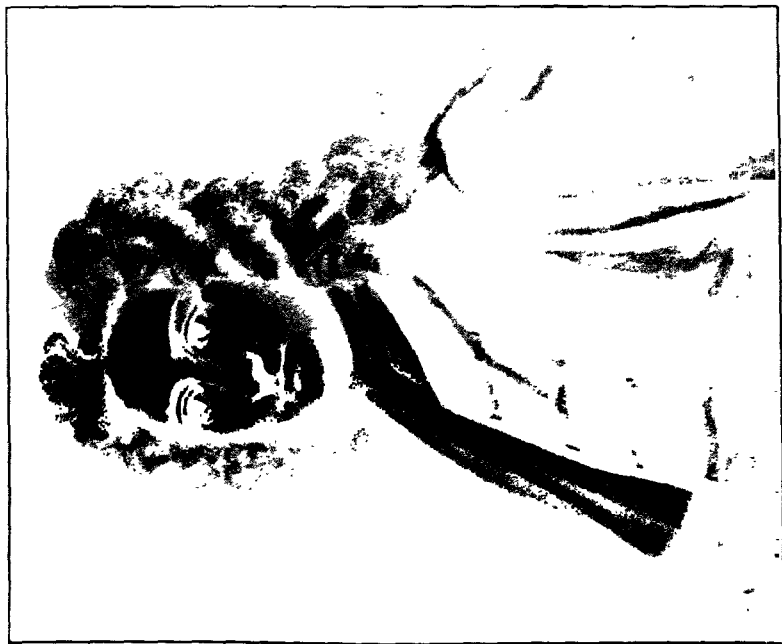
PLATE 1.

HALLEY'S HOUSE AT OXFORD, SHOWING HIS OBSERVATORY ON THE ROOF

[View Taken by L. A. Bauer, May, 1913.]

THE EARTH'S MAGNETISM.[1]

By L. A. BAUER,

Director, Department of Terrestrial Magnetism, Carnegie Institution of Washington.

[With 9 plates.]

It is indeed a great privilege and pleasure to give a lecture at Oxford, where Edmund Halley, whose name the founder has so wisely coupled with this lectureship, labored devotedly in the interest of science; and to be permitted, in some small measure, to pay the debt of terrestrial magnetism, and my own personal debt as well, to this illustrious investigator.

Halley's varied scientific activity and his wide sympathies were well set forth by the Halley lecturer[2] of two years ago, who had as his subject an astronomical one, " The stars in their courses." Last year's lecture,[3] " Large earthquakes," by that zealous pioneer, Prof. Milne, again exemplified both the scope of this lectureship and the fact that Halley's interest and achievements in geophysical science, though not generally so well known as his astronomical discoveries, were no less great. The subject of the lecture to-night, " The earth's magnetism," is one in which Halley's name stands out preeminent among the early students of the science. As it is a large subject and one in which there might be much discursive rambling, we shall do well to limit ourselves somewhat—to choose our starting point and then proceed in certain definite directions.

The adopted flag of the Chinese Republic consists of five stripes, partly because, as I am told, in China all good things are five—five seasons, five principal grains, five genii, five relationships that make up life, and five points of the compass, north, south, east, west, and center. For, to the Chinese, the starting-out point is as important as the point to which, or direction in which, a journey is made. So it also must be with us to-night.

According to the regulations governing this lecture, it is to be known as the "Halley lecture on astronomy and terrestrial magnetism." "Astronomy shall. include astrophysics, and terrestrial magnetism shall include the physics of the external and internal parts of the terrestrial globe." This lecture might, therefore, with propriety cover the whole range of investigation in terrestrial and cosmical magnetism. However, we must limit ourselves to those particular lines of research in our subject in which Halley himself was chiefly interested. It so happens that these are the very lines also in which I have been given the opportunity to continue and expand the work begun by him.

After Halley had made two attempts to establish a working theory respecting the distribution of terrestrial magnetism and the cause of its striking change with the lapse of years—the so-called secular variation—he must have reached the conclusion that the elusive problem of the earth's magnetism would be more profitably advanced by additional facts than by further speculation. That, paraphrasing Seneca, to avoid making a false calculation of matters. it were better to advise with nature rather than with opinion. Accordingly we find him setting out in October. 1698. in command of a sailing ship, the *Paramour Pink*, and cruising in her under orders from the British Government, back and forth, north and south, in the Atlantic Ocean for two years, observing almost daily, sometimes several times in a day. the angle which the compass needle makes with the true north and south line—the angle known to the man of science as the magnetic declination, to the mariner and surveyor as the " variation of the compass."

This is memorable as being the first scientific expedition sent out by any country with the specific object of improving existing knowledge regarding certain facts of the earth's magnetism. Not until somewhat over two centuries later did it occur again, that a sailing ship traversed the oceans with the chief purpose of making magnetic observations.[1] In July, 1905. there sailed from the port of San Francisco. Cal.. a chartered sailing yacht. the *Galilee*, sent under the auspices of the Carnegie Institution of Washington, on the sole mission to determine the magnetic elements at sea, for the benefit of both the mariner and the man of science, as was also the purpose of Halley's voyages. Four years later, in 1909. a specially built nonmagnetic vessel. likewise under the auspices of the Carnegie Institution of Washington. left New York for St. Johns, Newfoundland. and thence proceeded to Falmouth, along practically

[1] Valuable magnetic data have been secured by various expeditions since Halley's time, but either the magnetic work was merely incidental or formed part of a general scientific program, or was combined with some geographical object such as Arctic or Antarctic exploration—the memorable *Erebus* and *Terror* expeditions. for example.

the same track followed by Halley's ship. Since then this vessel, the *Carnegie*, has circumnavigated the globe and has repeatedly intersected the course of the *Paramour Pink* in the Atlantic Ocean.

In view of the historic interest thus attaching to Halley's magnetic expedition, it will be well worth our while to use this as our starting point or center, the fifth point in the Chinese compass. The instructions given Halley, as far as they pertained to his observational work, were as follows:

Whereas his Majesty has been pleased to lend his *Pink the Paramour* for your proceeding with hei on an expedition to improve the knowledge of the Longitude and variations of the Compasse, which shipp is now completely Man'd, Stored, and Victualled, at his Majesty's charge for the said Expedition; you are therefore hereby required and directed to proceed with her according to the following instructions:—

You are to make the best of your way to the southward of the Equator, and there to observe on the East Coast of South America, and the West Coast of Africa, the variations of the Compasse with all the accuracy you can, as also the true situation both of Longitude and Latitude of the Ports where you arrive.

You are likewise to make the like observations at as many of the islands in the seas between the aforesaid Coasts as you can (without too much deviation) bring into your Course; and, if the season of the year permit, you are to stand soe farr into the South till you discover the Coast of the Terra Incognita, supposed to lie between Mongolan's Straits and the Cape of Good Hope, which Coast you carefully lay down in its true position. In your return home you are to visit the English West India Plantations or as many of them as conveniently you may, and in them make such observations as may contribute to lay them down truely in their Geographicall Situation. And in all the Course of your voyage you must be carefull to omit no opportunity of noting the variation of the Compasse, of which you are to keep a Register in your Journal.

Curiously enough, Halley, though a prominent member of the Royal Society, never contributed a paper to it, nor did he publish anything elsewhere on these voyages of his, his observations, or resulting conclusions. Not until 1775 were Halley's journal and observations published, and then by Alexander Dalrymple in his "Collection of Voyages chiefly in the Southern Atlantick Ocean," from the manuscript in the possession of the Board of Longitude at London. Halley appears to have contented himself with laying down the results of his work on a chart entitled "A new and correct Sea Chart of the Whole World, showing the Variations of the Compass as they are found in the year 1700." This chart is often briefly referred to under the title " Tabula Nautica." The first edition, published probably in 1701, covered only the ocean—the Atlantic— traversed by Halley himself; for the later edition, as the chart was now to cover the greater part of the globe, he had to collect and utilize observations made by others. No printed reference to the early edition, either by Halley or by anyone else, prior to my dis-

covery of a copy in the British Museum in 1895 has thus far come to light. Yet this particular chart, termed by me the "Atlantic Chart," to distinguish it from the later one—the "World Chart"— is especially interesting, as it contains the routes followed by the *Paramour Pink*. Airy, when he reproduced Halley's "World Chart" in the Greenwich observations of 1869, was seemingly not aware of the "Atlantic Chart." [1]   (See pl. 2.)

The only description of Halley's chart by himself, thus far found, is that either attached to certain editions of the chart or contained on an accompanying leaflet. This, however, is very brief, and was chiefly intended to instruct mariners in the use of the chart. Halley points out that in certain regions where the "Curves" run suitably they may be used "to estimate the Longitude at Sea thereby." To his lines of equal "magnetic variation" he gave no distinctive name, simply referring to them as the "Curve Lines." Thus he says: "What is here properly New is the Curve Lines drawn over the several Seas to show the degrees of the Variation of the Magnetical Needle or Sea Compass." He does, however, use the term "Line of No Variation." For some time these lines were referred to by others as the "Halleyan lines." Hansteen a century later introduced the term "isogonic lines," which is now generally adopted. According to Hellmann, there is reason for believing that some attempts had been made before those of Halley to give on a globe or map a graphical representation of the direction in which a compass needle points. It is conceded, however, that Halley's was the first successful attempt; his "variation chart" was the first magnetic chart based on sufficient observational data to give it immediately both practical and scientific value.[2]

After the publication of his chart—the most important contribution to the observation material of terrestrial magnetism at the time—Halley made no further attempt to establish a theory or to improve on his early magnetic speculations. He appears finally to have adopted the view so clearly formulated by Prof. Turner[3]—

that the perception of the need for observations, the faith that something will come of them, and the skill and energy to act on that faith—that these qualities, all of which are possessed by any observer worthy the name, have at least as much to do with the advance of science as the formulation of a theory, even of a correct theory.

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[1] Those interested in the history of the Halley charts may be referred to the various articles by L. A. Bauer in Nature, May 23, 1895, p. 79, and in Terrestrial Magnetism, January, 1896, and September, 1913; the last-named reference also contains a compilation by J. P. Ault and W. F. Wallis of the magnetic results obtained on Halley's expedition.

[2] Mountaine and Dodson, the authors of the second and revised edition (1744) of the Halley Chart, and of the third (1756), published in connection with the latter a small tract, "An account of the Methods used to describe Lines on Dr. Halley's Chart of the terraqueous Globe, showing the variation of the magnetic needle about the year 1756 in all the known seas, London, 1758, 4°." This tract was again published in 1784.

[3] Pres. Address, Sec. A, Brit. Assoc. Adv. Sci., 1911.

PLATE 2.
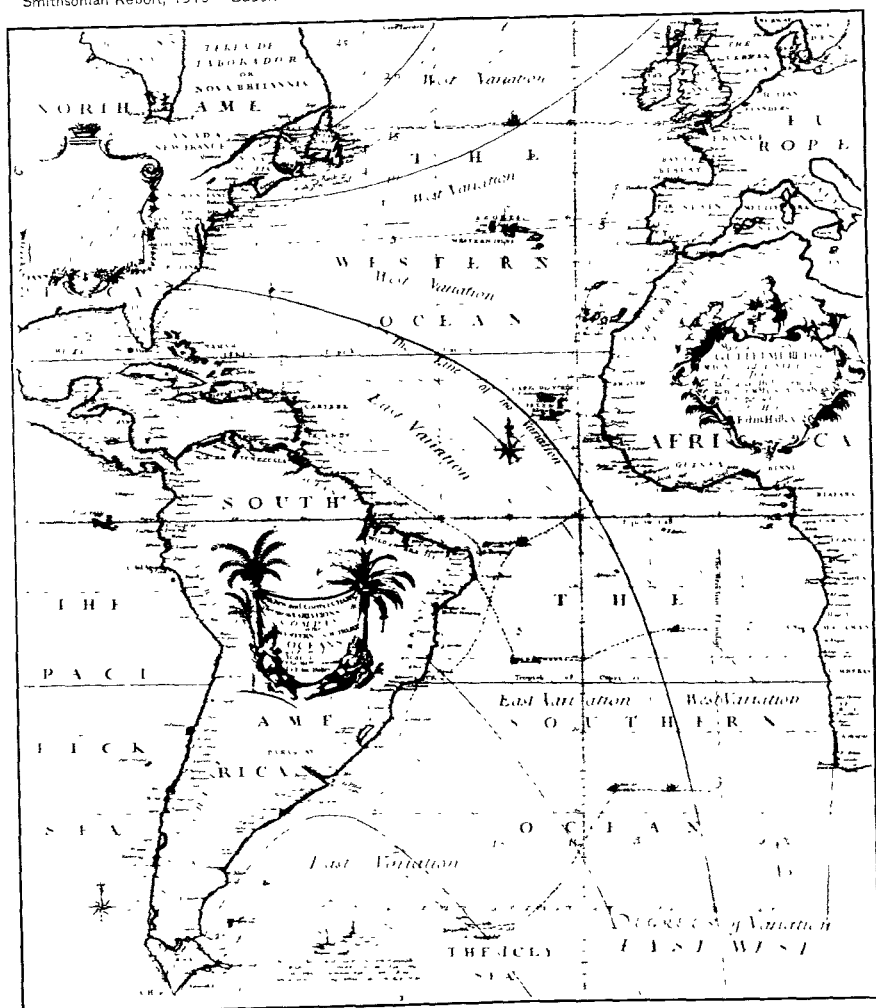
HALLEY'S ATLANTIC CHART OF THE LINES OF EQUAL MAGNETIC DECLINATION AS BASED ON
HIS OBSERVATIONS MADE DURING THE CRUISE OF THE "PARAMOUR PINK." 1698-1700.

[The dotted lines show the tracks followed by Halley's vessel.]

PLATE 3.
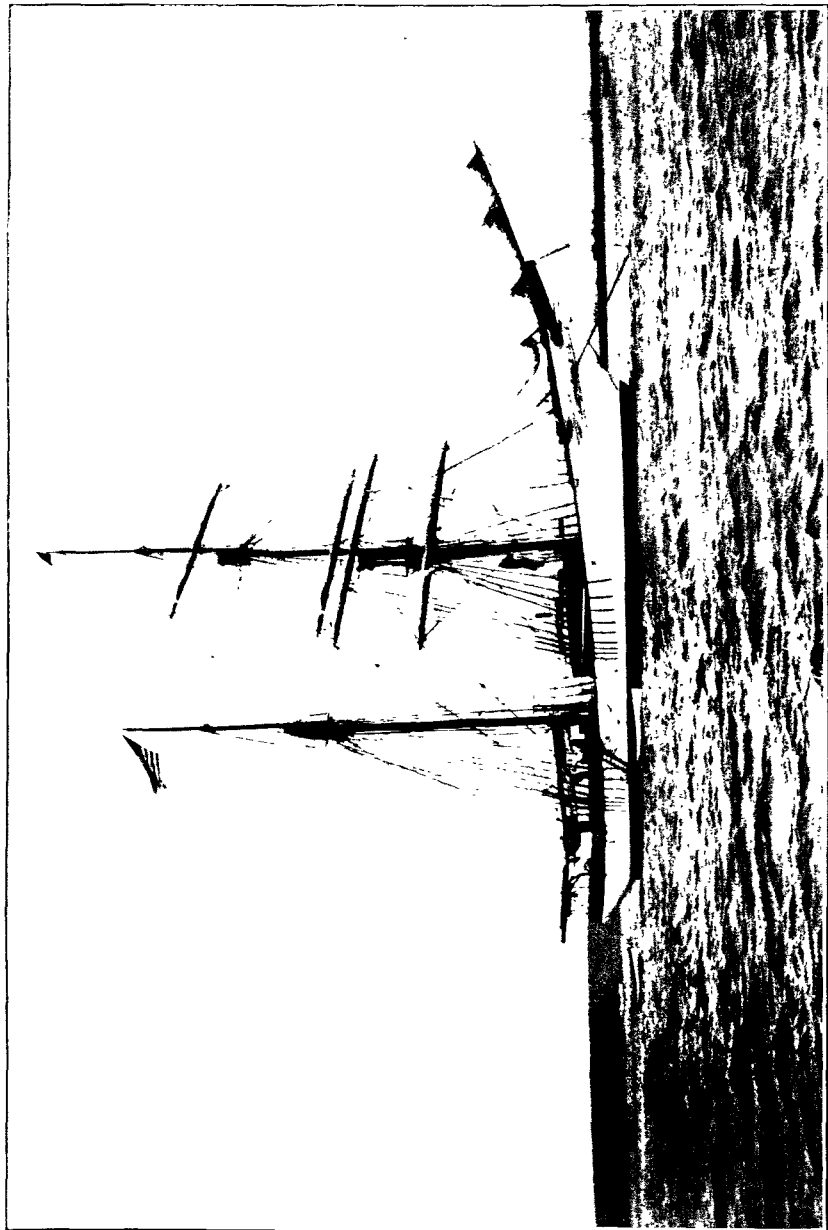
THE NON MAGNETIC YACHT "CARNEGIE" ON HER ARRIVAL AT FALMOUTH, ENGLAND, OCTOBER, 1909. HER TRACK FROM ST. JOHN'S, NEWFOUNDLAND, TO ENGLAND WAS PRACTICALLY THE SAME AS THAT OF HALLEY'S SHIP, THE "PARAMOUR PINK," IN 1699.

We find Halley embracing every occasion—

to recommend to all Masters of Ships and all others, Lovers of Natural Truths, that they use their utmost Diligence to make, or procure to be made, Observations of these Variations in all parts of the World, and that they please to communicate them to the Royal Society in order to leave as compleat a History as may be to those that are hereafter to compare all together and to compleat and perfect this abstruse Theory.

Consulting the minutes of the Royal Society, it is found that Halley communicated, from time to time, the results of magnetic observations received from various expeditions, as also the values of the magnetic declination observed by himself, at London, viz:

1701, May 7.—Mr. Halley tried the experiment of the Variation of the Needle this day with the two needles he had with him in his late Voyage; and by the one the Variation was 7° 40'; by the other, 8° 00' W.

1702, July 8.—Mr. Halley observed the Variation of the Needle, which was found to be 8½° Westward, or very near it.

1716, May 24.—Dr. Halley reported that he had drawn a Meridian Line on the stone erected in the Society's yard before the repository and that the Variation was found at present to be full twelve degrees.

These observations of the magnetic declination of 1701, 1702, and 1716 are perhaps printed here for the first time and are not found in any of the compilations of magnetic declinations at London published thus far. Only Halley's earlier observations, namely, those of 1672 (2° 30' W.), 1683 (4° 30' W.), and of 1692 (6° 00' W.), having been given by Halley himself in his printed papers of 1683 and 1692, have become known to compilers.

CHANGE OF THE MAGNETIC DECLINATION IN THE ATLANTIC OCEAN SINCE HALLEY'S CHART.

In view of the fact that the two vessels—the *Paramour Pink* and the *Carnegie*—both being primarily dependent for their motive power upon the prevailing winds in the Atlantic Ocean, have followed nearly identical courses, it will be a matter of no little interest to compare the values of the magnetic declination given on Halley's chart for 1700 with those obtained by the *Carnegie* in her cruises in 1909–10. We find first that over the entire Atlantic, from 50° N. to 40° S., the north end of the compass needle in 1910 was to the west of the compass direction of 1700 by amounts varying with locality. Thus for various important ports the approximate change was as follows: New York, 2°.9 W.; St. Johns, Newfoundland, 14°.6 W.; Falmouth, England, 10°.4 W.; Funchal, Madeira, 15°.6 W.; Bermuda, 10°.5 W.; Porto Rico, 7°.6 W.; Para, Brazil, 14°.6 W.; Rio de Janeiro, 20°.8 W.; Buenos Aires, 13°.0 W.; Cape Town, 16°.2 W.

If we follow a line passing through the points of maximum change in the Atlantic Ocean, we find for the following points:

Values of the magnetic declination in 1700 and 1910.

Latitude.	Longitude.	Paramour Pink, 1700.	Carnegie, 1910.	Secular change (1910–1700).
50°.4 N.	30°.4 W.	11°.3 W.	29°.5 W.	18°.2 W.
35°.9 N.	47°.0 W.	4°.0 W.	22°.1 W.	18°.1 W.
21°.0 N.	30°.9 W.	0°.6 W.	19°.2 W.	18°.6 W.
5°.9 N.	35°.8 W.	2°.5 E.	16°.5 W.	19°.0 W.
40°.6 S.	25°.2 W.	10°.7 E.	17°.5 W.	28°.2 W.

We see, accordingly, that the compass direction, in the course of time, suffers large changes; for the region and time interval considered the changes vary from about 3° off New York to 28° in the Atlantic Ocean about midway between Buenos Aires and Cape Town. Even these amounts may not represent the total or maximum change during the period in question.

Equally to be noted with these large changes with time is the important fact that the amount of change is as dependent upon locality as is the prevailing compass direction itself, which for over four centuries has been known to be anything but " true to the pole."

We have thus had impressed upon us this important fact: Two sailing vessels cruising in the Atlantic Ocean from port to port— the one in 1700 and the other in 1910—were forced by the prevailing winds to follow very closely identical courses. If, however, these two vessels had been directed to follow certain definite magnetic courses, and if we may suppose that they had such motive power as to render them independent of the winds, then their respective paths would have diverged considerably. For example, if the *Carnegie* had set out from St. Johns. Newfoundland, to follow the same magnetic courses as those of the *Paramour Pink*, instead of coming to anchor in Falmouth Harbor (pl. 3), she would have made a landfall somewhere on the northwest coast of Scotland. In brief, while the sailing directions as governed by the winds over the Atlantic Ocean are the same now as they were during Halley's time, the magnetic directions or bearings of the compass that a vessel must follow to reach a given port have greatly altered. To quote from the suggestive essay on terrestrial magnetism by John F. W. Herschel: [1]

The configuration of our globe—the distribution of temperature in its interior, the tides and currents of the ocean, the general course of winds and the affections of climate—whatever slow changes may be induced in them by those revolutions which geology traces—yet remain for thousands of years appreciably

[1] Essays from the Edinburgh and Quarterly Reviews, with addresses and other pieces, by Sir John F. W. Herschel, London. 1857, pp. 69–70.

constant. The monsoon, which favors or opposes the progress of the steamer along the Red Sea, is the same which wafted to and fro the ships of Solomon. Eternal snows occupy the same regions and whiten the same mountains, and springs well forth at the same elevated temperature, from the same sources, now as in the earliest recorded history. But the magnetic state of our globe is one of swift and ceaseless change. A few years suffice to alter materially and the lapse of half a century or a century to obliterate and completely remodel the form and situation of those lines on its surface which geometers have supposed to be drawn in order to give a general and graphical view of the direction and intensity of the magnetic forces at any given spoch.

REGARDING LONGITUDE DETERMINATIONS AT SEA.

One important result of Halley's voyage and of the publication of his chart was the awakening of renewed interest in the improvement of methods for determining the longitude at sea. Recalling Halley's instructions, we note that one of the objects of his expedition was " to improve the knowledge of the Longitude."

When the discovery was made that the magnetic declination varied from place to place, the idea immediately occurred to Columbus, as also to Cabot, that the longitude might be determined at sea by means of this fact. Antonio Pigafetta, who accompanied Magellan on his first voyage around the world in 1522, definitely proposed, in his book on navigation, this method of longitude determination. The line of no magnetic declination, which at that time passed through the Azores, was regarded as the natural meridian from which to count longitude. When later it was found, as was first remarked by J. de Acosta in his Historia Natural: Sevilla, 1590, that there were four such lines, it was again thought that these quadrantal divisions could be utilized for reckoning longitudes. In 1674 Charles II appointed a commission to examine into the pretensions of a scheme devised by Henry Bond for ascertaining the longitude by the " variation of the compass."

Halley's chart, however, definitely showed that it would be, in general, futile to attempt to determine the longitude by means of an element so variable and so irregular in its distribution as is the magnetic declination. Nevertheless, the hope that some magnetic phenomenon might yet serve to aid in the solution of this problem did not die immediately.

In 1721 we find William Whiston, Newton's successor at Cambridge, installing dip circles on a number of vessels, with instructions to observe diligently the magnetic dip in order to determine whether by means of this element the longitude could be better found at sea than by the magnetic declination; he likewise hoped thus to determine the latitude at sea.

It is also interesting here to note that when Dr. Johnson was at Oxford, he gave in 1756 to the Bodleian Library a thin quarto of 21 pages, entitled "An Account of an Attempt to ascertain the

Longitude at Sea by an exact Theory of the Variation of the Magnetical Needle, etc.," by Zachariah Williams, published at London in 1755; Johnson entered it with his own hand in the library catalogue. Boswell relates that Johnson himself wrote the English version for Williams, and, in order to make it more extensively known, also had an Italian translation prepared by his friend, Signor Baretti.

For fully three centuries the idea that the longitude could be determined at sea with the aid of some magnetic element, though proved to be fallacious, served a most useful purpose by furnishing the necessary incentive to observe the magnetic elements. This is a striking illustration of the soundness of the position taken by Maxwell when he said: " I never try to dissuade a man from trying an experiment; if he does not find what he wants, he may find out something else." It was indeed true of these magnetic longitude seekers that they failed in their purpose, but they contributed data of inestimable value to the advancement of our knowledge of the earth's magnetism.

Before leaving this subject it might be said that Halley himself proposed an astronomical method for solving the longitude problem, and, with Newton, he was responsible for the act of 1714 offering a reward to any person who should devise a satisfactory method for the determination of the longitude at sea. He also improved some of the instruments used in navigation.

Another result of Halley's various voyages deserves mention here, though not immediately concerned with the subject of our lecture, namely, his theory of the cause of the trade winds.[1] On certain editions of his Variation Chart there was given, in addition to the lines of equal magnetic variation, a " View of the Generall and Coasting Trade Winds and Monsoons or Shifting Trade Winds."

COMPLEXITY OF THE EARTH'S MAGNETISM.

Reference has already been made to Halley's attempts, before his magnetic expedition, to establish a theory respecting the phenomena of the compass needle. Thus in 1683 he published in the Philosophical Transactions of the Royal Society "A Theory of the Variation of the Magnetical Compass," and in 1692, in the same Transactions, "An Account of the Cause of the Change of the Variation of the Magnetic Needle."

In these papers Halley rejected the hypothesis which had been accepted up to that time, and on the basis of which elaborate tables of the magnetic declination had been constructed by previous investigators, namely, that the directions assumed by a compass needle in various parts of the earth could be accounted for by a simple magnet-

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[1] See Miscellanea Curiosa, vol. I, pp. 61–80, and pl. 2.

ization parallel to a diameter so that the magnetic poles would be diametrically opposite to each other. While the conclusion reached by him that " the whole Globe of the Earth is one great Magnet having four Magnetical Poles, or Points of Attraction, near each Pole of the Equator Two," has, in a certain sense, been found to be incorrect nevertheless, this view appears to have been the first definite recognition of the heterogeneity or complexity of the earth's magnetic condition.

The increased knowledge gained from magnetic surveys since Halley's time has taught that the more carefully a country has been explored, i. e., the nearer together the points at which the magnetic elements have been determined, the greater is the number of irregularities usually shown by the so-called isomagnetic lines; indeed, regions have been found where no system of lines can adequately and correctly represent the prevailing magnetic conditions. We have learned that the regularities in the distribution of the earth's magnetism, far from being normal features, as was once thought, are, instead, the abnormal ones, and that the irregularities are the normal and to-be-expected phenomena.

The magnetic forces, as measured at any given point on the earth's surface, appear, according to various analyses, to be the resultant effects of (1) a general or terrestrial magnetic field due to the general magnetic condition of the whole earth; (2) a general terrestrial disturbing cause which distorts at the place of observation the general magnetic condition of the earth; (3) a disturbing effect continental in extent; (4) a regional disturbance effect due to low-lying magnetized substances; and (5) a local disturbance due to the magnetized masses in the immediate vicinity.

No formula has as yet been established which will represent the observational facts within the error of observation, in fact not even with sufficient accuracy for the practical purposes of the surveyor and of the mariner.

THE EARTH'S MAGNETIC POLES.

We have noticed that Halley, as the result of his study of the observations of the magnetic declination, as far as they had become known up to 1683, reached the conclusion that the earth had " four Magnetical Poles or Points of Attraction." Some confusion has arisen as to the precise meaning which Halley attached to his " poles." Owing to his alternative term—" Points of Attraction "—certain eminent writers have sought to identify Halley's supposed four magnetic poles with the four foci of maximum total magnetic force, whose existence appeared to be indicated when, near the middle of the nineteenth century, it became possible to construct a chart of the lines of equal magnetic force. By this incorrect inference these

authors have unwittingly credited Halley with a discovery which, in the absence at the time of any observation whatsoever respecting the strength of the earth's magnetic force, he could not possibly have made. The real merit and purport of Halley's deduction has thereby been obscured. The observation material at Halley's disposal, before he himself enriched the material during his voyages, consisted of some miscellaneous observations of the compass direction and a few values of the magnetic dip. As has been said, there were no observations of the magnetic force, for the art of measuring this element had not yet become known.

Scrutinizing carefully his scanty observation material, Halley noticed that the direction of the compass needle did not change from place to place in the simple way it would if, for example, the earth had two magnetic poles diametrically opposite each other. In the latter case the needle would set itself tangent to the great circle passing through the magnetic poles and the place of observation. If, then, the compass direction were known at two places sufficiently far apart the points of intersection of the two great circles drawn respectively tangent to these compass directions would be the two diametrically opposite magnetic poles. It is such points of intersection—"points of convergence," as Hansteen later called them—which Halley had in mind as "Magnetic Poles." He was the first to perceive clearly the fact—abundantly verified since—that the various points of convergence as found from successive pairs of compass directions, in the manner just described, do not fall together as they should on the basis of a simple or regular magnetization of the earth. However, it appeared to Halley, and the same conclusion was reached over 100 years later by the illustrious Norwegian magnetician, Hansteen, that the several points of convergence grouped themselves in a general way about two main centers—

near each Pole of the Equator Two, and that in those parts of the World which lie near adjacent to any one of those Magnetical Poles the Needle is govern'd thereby, the nearest Pole being always predominant over the more remote.

It will not be well to lay greater stress upon this deduction nor upon those in his 1692 paper, where he seeks to account for the existence of his four "Magnetic Poles" and for the secular variation than to say that Halley drew the best possible conclusions the material at his disposal permitted. In fact, his conclusions were not materially improved upon until a century and a half later, when a much more complete knowledge of the distribution of the earth's magnetism had been gained and when the various mathematical attempts which had been made to compute the magnetic elements on the basis of more or less intricate hypotheses as to the earth's magnetization, had been found to be inadequate. Some later investigators, indeed,
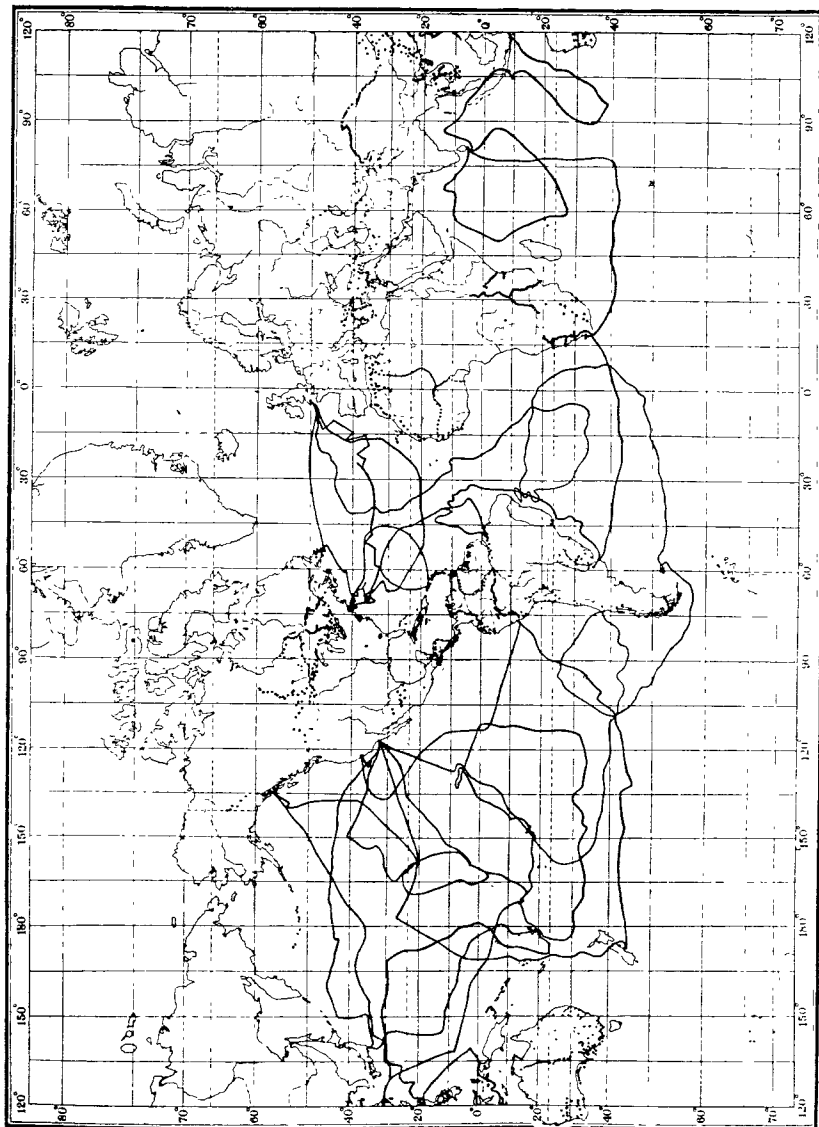
MAP SHOWING THE TRACKS FOLLOWED BY THE "GALILEE" IN THE PACIFIC OCEAN, 1905-1908; AND BY THE "CARNEGIE" IN THE ATLANTIC, PACIFIC, AND INDIAN OCEANS, 1909-1913.

[Total mileage of both vessels for 1905 to 1913 was about 164,000. Dots show land magnetic stations established by the Carnegie Institution of Washington, 1905-1913]

PLATE 5.
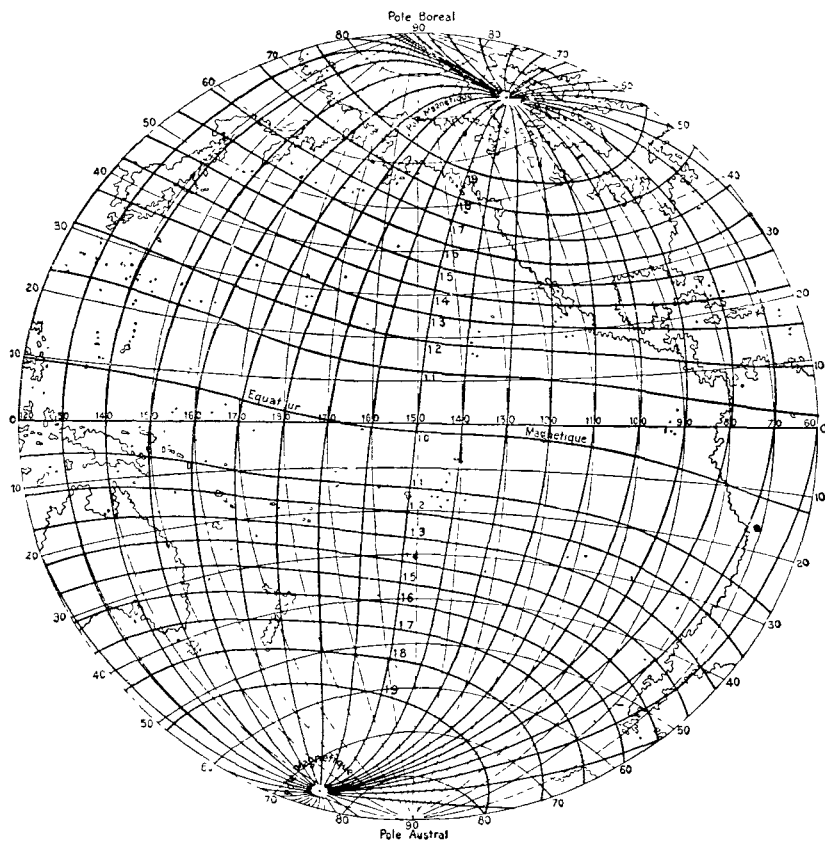
DUPERREY'S CHART OF THE MAGNETIC MERIDIANS FOR 1836.

[If the earth were uniformly magnetized, its magnetic poles would be located diametrically opposite one another. However, because of the complexity of the earth's magnetic condition, the chord connecting the two poles passes through the earth 750 miles distant from the center.]

might have spared themselves considerable pains had they previously familiarized themselves more thoroughly with Halley's work.

When we to-day speak of the earth's magnetic poles, it is generally recognized that those points on the earth's surface are meant where the dipping needle stands precisely vertical and where the magnetic dip is accordingly 90°. This definition permits, with the aid of the dipping needle, of a precise determination of the magnetic poles, though, of course, it must not be understood that these poles are mathematical points; the area over which the dip may be found to be 90°, within the instrumental means of determination, may, in fact, be several miles square. A more or less extensive magnetic survey of the region round about would be required to eliminate the possibility of disturbing influences owing to local deposits of iron ore. At these " Poles," since the magnetic force exerted by the earth is all up and down, with no side component, a compass needle would have no directive force acting upon it. Some distance before reaching the magnetic pole it would become sluggish, and directly over the pole itself it would be of no more use than a brass needle to indicate any definite direction. (For chart of the magnetic meridian, see pl. 5.)

Excluding for the present the purely " local magnetic poles " (pl. 8, fig. 2) caused by extraordinary local deposits of attracting masses, all observations to date show that there are but two such points (or areas) where the dipping needle stands vertical, one in the Northern Hemisphere, located by Capt. James Clark Ross in June, 1831, in latitude 70°.1 north and longitude 96°.8 west (pl. 6, fig. 2),[1] and the other in the Southern Hemisphere, lying, according to the observations of the recent Antarctic expeditions, about in latitude 72°.7 south and longitude 156° east. The magnetic poles, therefore, are, on the average, about 1,200 miles from the geographical poles. Owing to the asymmetrical distribution of the earth's magnetism, the magnetic poles are not diametrically opposite each other, even if the positions given applied to the same year; in fact, the perpendicular distance from the earth's center to the chord connecting the magnetic poles is about 750 miles.

Let us suppose, now, that one explorer starts out from Oxford, where the compass points at present about 16° west, and follows always the direction shown by the north end of the compass needle, whereas another starts north from Washington, where the compass bears about 5° west, and follows likewise the direction of the compass needle. The paths thus traced out by them are the so-called " magnetic meridians," which, owing to the irregular way in which the earth is magnetized, would not be straight lines or arcs of great

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[1] During Capt. Amundsen's completion of the Northwest Passage, 1903–1907, he also made observations with a view to locating the north magnetic pole. but the resulting position has not yet been published.

circles, but more or less devious lines. Could these magnetic meridians be followed into the Arctic regions, they would be found to intersect at the north magnetic pole.

Owing to the irregular distribution of the earth's magnetism, the points of greatest intensity of the total magnetic force depart widely in their locations from the magnetic poles. Thus there are in the Northern Hemisphere two distinct maxima of total magnetic force, one in the northeast of Siberia and the other in Canada to the southwest, approximately, of Hudson Bay. A magnetic survey of the latter region is being made this summer by an expedition sent out by the Department of Terrestrial Magnetism.

DO THE MAGNETIC POLES MOVE?

Possibly the most frequent question asked of those engaged in magnetic work is: "Do the magnetic poles move with the lapse of years, and if so, why?" Unfortunately, as has already been shown, there are no direct observations as yet on which to base a definite statement. But it would be singular, indeed, if these points remained fixed and were not affected by fluctuations such as are now known from three centuries of observations to exist in every one of the earth's magnetic phenomena. It is quite possible, in fact, that the magnetic poles pass through certain motions even in the course of a day or suffer displacements during magnetic storms.

The diagram (pl. 6, fig. 1) shows the changes in the direction of the compass (magnetic declination), as well as in the direction of the dip needle (magnetic inclination), as far as known. for London, Baltimore, and Boston. Imagine yourself, if you will, standing at the center of a great magnetized needle so suspended as to be free to assume the direction actually taken by the lines of magnetic force at the place of observation, and let us suppose you are looking toward the north-pointing end of the needle. Could you gaze long enough, you would see a curve described in space by the observed end of the needle. This curve would lie on a sphere whose radius is the half-length of the suspended needle and for graphical representation we may take a central projection of it on a plane tangent to the sphere at about the middle point of the curve. The curves here given were constructed by me with the aid of the accumulated observations up to about 1895; the course followed by the needle since 1895 will be discussed later. (Pl. 6, fig. 1.)

A number of interesting and instructive facts follow from these curves; time will permit us to give our attention only to the chief ones. It is seen that at London, for example, the compass reached its maximum easterly direction of about 11° in the year 1580, hence during the middle of Queen Elizabeth's reign; thereafter the easterly
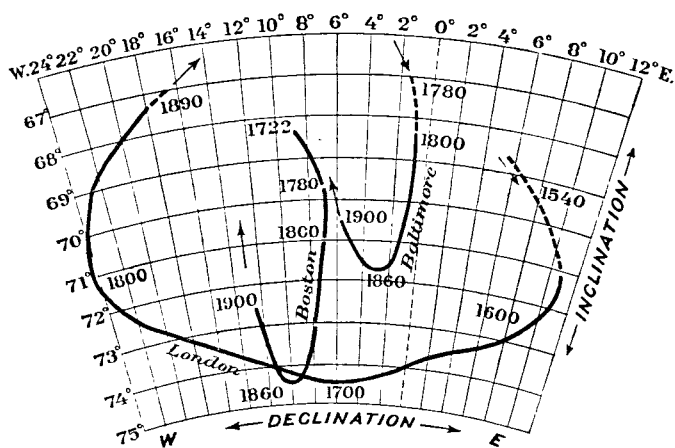
FIG. 1.—CURVES SHOWING THE SECULAR CHANGE IN THE MAGNETIC DECLINATION AND
IN THE DIP AT LONDON, BOSTON, AND BALTIMORE.

[Drawn for supposed length of freely suspended magnetic needle of about 50
centimeters, or nearly 20 inches.]
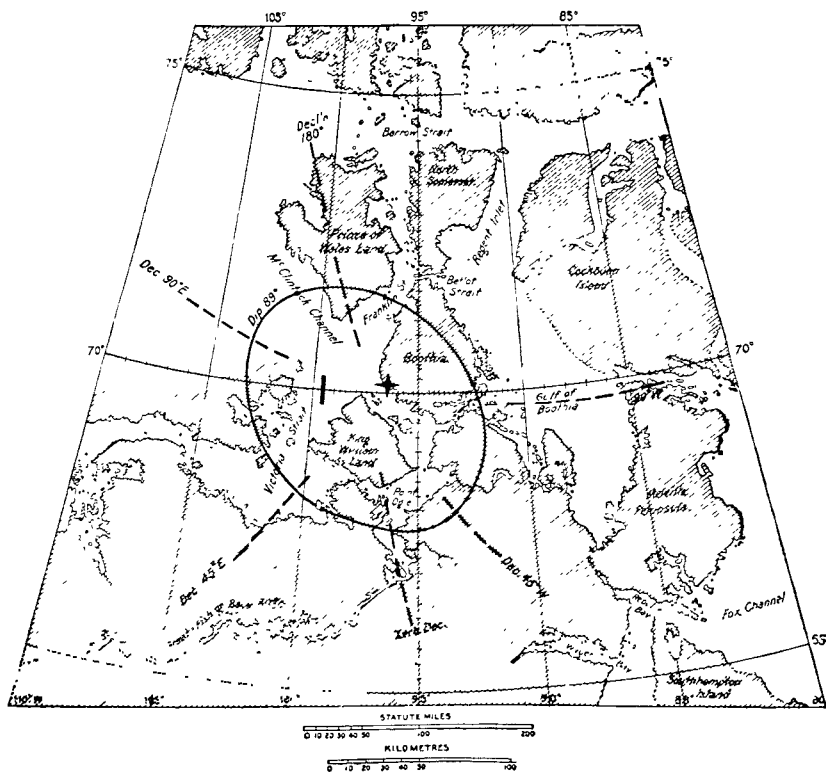
FIG. 2.—MAP OF REGION ABOUT THE MAGNETIC NORTH POLE, INDICATING HOW THE
COMPASS POINTS IN THE VICINITY.

[The earth's magnetic poles are, on the average, 1,200 miles distant from the geographical poles.]

PLATE 7.

Smithsonian Report, 1913 - Bauer
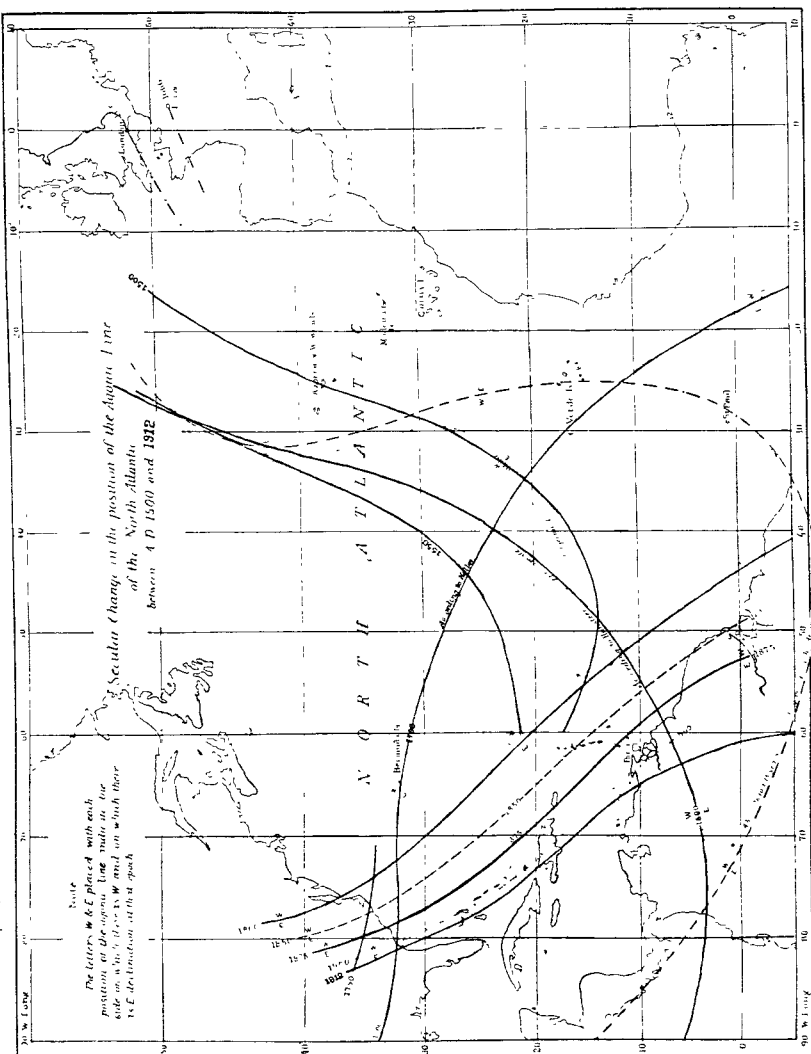
SECULAR CHANGE IN THE POSITION OF THE AGONIC LINE (LINE OF NO MAGNETIC DECLINATION) OF THE NORTH ATLANTIC OCEAN, 1500 TO 1912.

direction began to diminish until about 1658, the year of Cromwell's death, when the needle bore due north and then swung over to the west, continuing to do so until it reached a maximum westerly direction of somewhat over 24° in about 1812. Hence in the interval of about 232 years (1580–1812) the compass direction changed at London from 11° E. to 24° W., or 35°. At the present time it points about 15½° W., or nearly 9° less than in 1812, and a most interesting question doubtless immediately occurs to all of us: Will the freely suspended magnetic needle ever return precisely to a direction taken at some previous time, or is there any definite cycle of changes which will repeat itself from time to time?

Here again no wholly definite answer can be given, primarily because of the fact, as will be seen from the diagram, that, if there be such a cycle, it embraces many more years than are covered thus far by the interval of observation. For some European stations, e. g., Paris and Rome, the observation interval is somewhat longer than at London, but still not long enough for definite prediction as to the future course of the magnetic needle.

The diagram shows also that in the United States the changes in the compass direction, as far back as they are known, have not been as great as those during the same time at London. Thus, at Baltimore, for example, the compass appears to have reached a maximum westerly amount of about 6.1° near 1670, and a minimum of ⅔° in 1802, after which, instead of passing through a zero value as at London in 1658, and swinging to the eastward, it turned back and began to increase its westerly direction until at the present time the amount is about 6½°. Thus, at this station the compass direction passed from a maximum to a minimum in about 132 years and the total change was but 5½°, or only one-sixth to one-seventh of that at London.

In brief, the facts revealed by the known compass changes in my country can not be brought in harmony with those witnessed in your country, unless we assume that the length of the cycle of complete change is many times longer than merely twice the period between a maximum and a minimum bearing of the compass.. There are evidences futhermore, into which we can not go here, to indicate that the cycle of change at one station is not of the type which would result were we to close the apparently nearly completed curve at London by uniting the two ends in some simple manner. On the contrary, the evidences point to cycles within cycles and to the probability that the secular variation curve, instead of being a single closed curve, may consist of smaller loops within a larger one, etc.; it is even questionable whether there ever will be exact closure of the curve.

There is at present another matter of no little interest with regard to England which should be pointed out here. It will be seen from the London curve that the dip of the needle below the horizon reached its maximum amount of 74.4° in about 1688. At this time the compass changed its direction the maximum amount of 13′ per year. The curve would seem to indicate that the time of a minimum dip is now approaching; this phase has already occurred at Pawlowsk and seems to be now taking place at Potsdam and is traveling westward. Whether it will reach London and when can not be answered definitely. However, it is a matter of no little interest, in this connection, to observe that the annual amount of change in the compass direction has in recent years received a remarkable acceleration in this part of the earth. Thus, as is shown by the magnetic observatory records, it has almost steadily risen from 4′ per year in 1902 to about 9′ per year in 1912. Whether this portends an early approach of the phase of minimum dip at London is one of the many interesting questions continually arising respecting the perplexing phenomena of the earth's magnetism. The course of the needle since 1890 has been about as shown by the arrow; thus in 1910 the magnetic declination was approximately 15.9° W. and the dip was 66.9°.

One thing more. Note that for each of the three curves as far as drawn, the motion of the freely suspended magnetic needle has been clockwise, i. e., the same as the motion of the hands of a watch. This fact, as shown by the curves in other parts of the world, constructed with the aid of the available observations, appears to hold generally in both the Northern and Southern Hemispheres, except for certain retrograde motions which thus far have not been of the same extent as the direct one, although, of course, it is not affirmed that they may not become so later. Such retrograde motions are at present being experienced in certain parts of the United States. Thus, for example, the compass pointed in 1910 6.25° W. at Baltimore and 13.35° W. at Boston, and in the same year the magnetic dip was 70.9° at Baltimore and 73.1° at Boston. If we plot these values on the diagram, we shall find that the curves for Boston and Baltimore, instead of progressing in the direction of the arrows, passed through a secondary crest about 1895 and then bent over to the left: how long this will continue can not be foretold.

The question as to the cause of the remarkable changes from time to time in the earth's magnetic condition, as indicated by these curves, has been a fruitful source of speculation since 1634, when Gellibrand definitely proved the fact that the compass direction varies from year to year. Some of the best minds have been engaged with the discovery of the cause, but the riddle is still unsolved. Hence as regards the actual motions of the earth's magnetic poles and the

precise cause or causes, we may still say with Halley that these are "Secrets as yet utterly unknown to Mankind, and are reserv'd for the Industry of future Ages."

A mathematical analysis of the accumulated material shows that, in order to find an adequate explanation of the secular variation of the earth's magnetism, we must reckon with systems of magnetic or electric forces having their seats both below and above the earth's crust. There would also appear to be some evidence that in addition to a motion of the magnetic poles or magnetic axes of the earth, we may also have to take into account a possible diminution in the earth's magnetic moment or intensity of magnetization.

THE ORIGIN OF THE EARTH'S MAGNETISM.

Before concluding this lecture, we ought, perhaps, in the few minutes remaining, to say something regarding the status of the ever-recurring question as to the origin of the earth's magnetism. Assuming that the magnetism of our planet is uniformly distributed throughout its mass, it is found that the average intensity of magnetization is only about one ten-thousandth of very highly magnetized hard steel. Prof. Fleming, in his very suggestive popular lecture on the "Earth, a great magnet," given at the meeting in 1896 of the British Association for the Advancement of Science, made this statement:

Taken as a whole, the earth is a feeble magnet. If our globe were wholly made of steel and magnetized as highly as an ordinary steel-bar magnet, the magnetic forces at its surface would be at least 100 times as great as they are now. That might be an advantage or a very great disadvantage.

If, however, we could penetrate the earth's crust we would find at a distance of only about 12 miles a temperature so great that, according to present laboratory facts, all magnetization would necessarily cease. Hence, if the earth's magnetic field arises from an actual magnetization of the substances composing the earth, these substances must be confined within a comparatively thin shell. But the question immediately arises: Is this argument correct? May it not be that just as the point of liquefaction is raised by increased pressure, so is also the critical temperature of magnetization. It may thus occur that the effect due to increase of pressure with depth of penetration more than balances that due to increased temperature. There are at present no wholly decisive experiments which may be drawn upon to answer this query.

The hypothesis that the earth may be an electromagnet also meets with difficulties when we attempt to account for the origin, direction, and maintenance of the required currents. In spite of the accumulated facts of over three centuries, we are still unable to say definitely to what the earth's magnetic field is really due. Perhaps we may

not be able to solve the riddle until the physicist answers for us the questions: What is a magnet? What is magnetism in general?

In the Devil's Dictionary by Ambrose Bierce, published in 1911, the following definitions are given: "Magnet, n.—Something acted upon by magnetism. Magnetism, n.—Something acting upon a magnet." In explanation the author cynically remarks: "The two definitions immediately foregoing are condensed from the works of 1,000 eminent scientists, who have illuminated the subject with a great white light, to the inexpressible advancement of human knowledge."[1]

A line of thought first suggested by Schuster and Lord Kelvin, that every large rotating mass, due to an as yet undiscovered cause, may be a magnet, should be considered in conclusion, though we may do so but briefly. If this be true, then magnetism is not confined to our planet alone, but all celestial bodies are surrounded by magnetic fields. Thus far no laboratory experiment, possibly owing to lack of required sensitiveness in the measuring instruments, has detected any magnetic field arising solely from rotation. Schuster and Swann have recently discussed the character and magnitude of the effects from the possible causes which may operate if the earth's magnetic field be related in some manner to its rotation.

In 1900–1903 Sutherland propounded a theory for the origin of the earth's magnetism, which, briefly stated, is this: We know that electricity is an essential constituent of matter, and that in every atom, if it be electrically neutral, there are equal amounts of negative and positive electricity. So with the whole earth. Since it is almost electrically neutral, suppose that the total negative charge, while practically equal to the total positive one, occupies a slightly different volume from that of the positive charge, or, in brief, that the volume densities of the two body charges differ slightly, then, because of the rotation of the electric charges with the earth, a magnetic field arises. I have recently repeated Sutherland's calculations and, as I had previously found that the earth's intensity of magnetization increased systematically toward the Equator, I have included a term to represent such a possible effect. The computations show that to satisfy the known phenomena of the earth's magnetism, the volume density of the negative charge must be smaller

[1] These definitions and accompanying remarks may have had their origin in the following interesting anecdote told in the American Review of Reviews for August, 1909, of the late Prof. Simon Newcomb, by Mr. A. E. Bostwick, associate editor of the Standard Dictionary. Of the definitions in physical science for this dictionary Newcomb had general oversight, and on one occasion he took exception to the definitions framed for the words "magnet" and "magnetism" as based, in the absence of authoritative knowledge of the causes, simply upon the properties manifested by the things. After writing and erasing alternately for an hour or more, he finally confessed, however, with a hearty laugh, that he himself could offer nothing better than the following pair of definitions: "Magnet, a body capaple of exerting magnetic force; and magnetic force, the force exerted by a magnet."

PLATE 8.
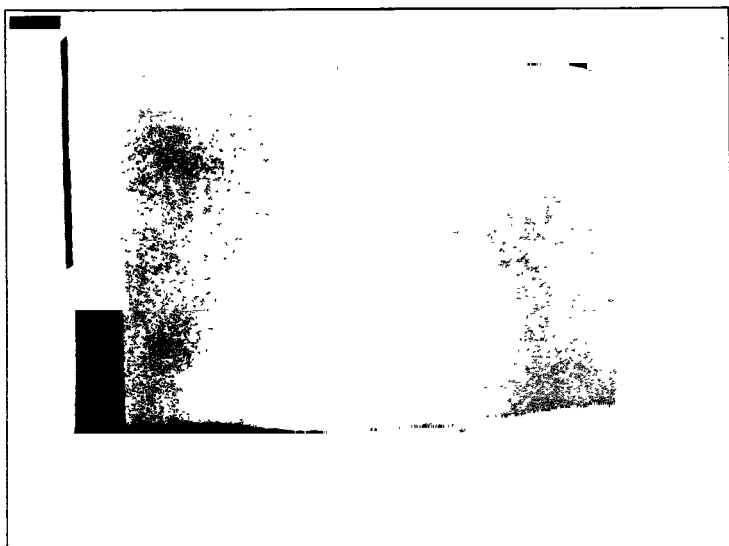
FIG. 1.—THE AURORA BOREALIS AS FIRST SUCCESSFULLY PHOTOGRAPHED BY
PROF. CARL STOERMER.

[Halley was the first to suggest a connection between polar lights and the earth's
magnetism.]
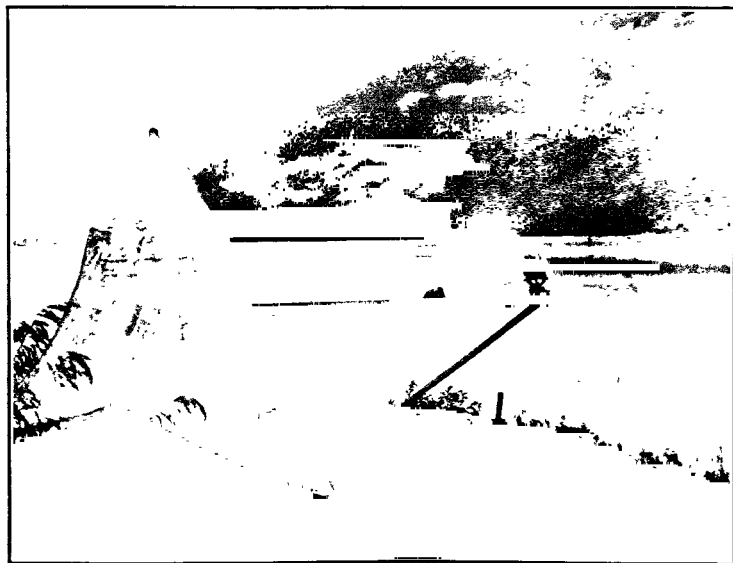
FIG. 2.—A LOCAL MAGNETIC NORTH POLE AT TREADWELL POINT, NEAR
JUNEAU, ALASKA, AS DISCLOSED BY L. A. BAUER'S OBSERVATIONS IN
1900 AND 1907.

[In the center of the tent the dipping needle stood vertical with the north end down,
and the compass reversed its direction when carried from one side of the tent to
the other. Ships' compasses, a mile away, in Gastineaux Channel, are deflected
about 11°.]

PLATE 9
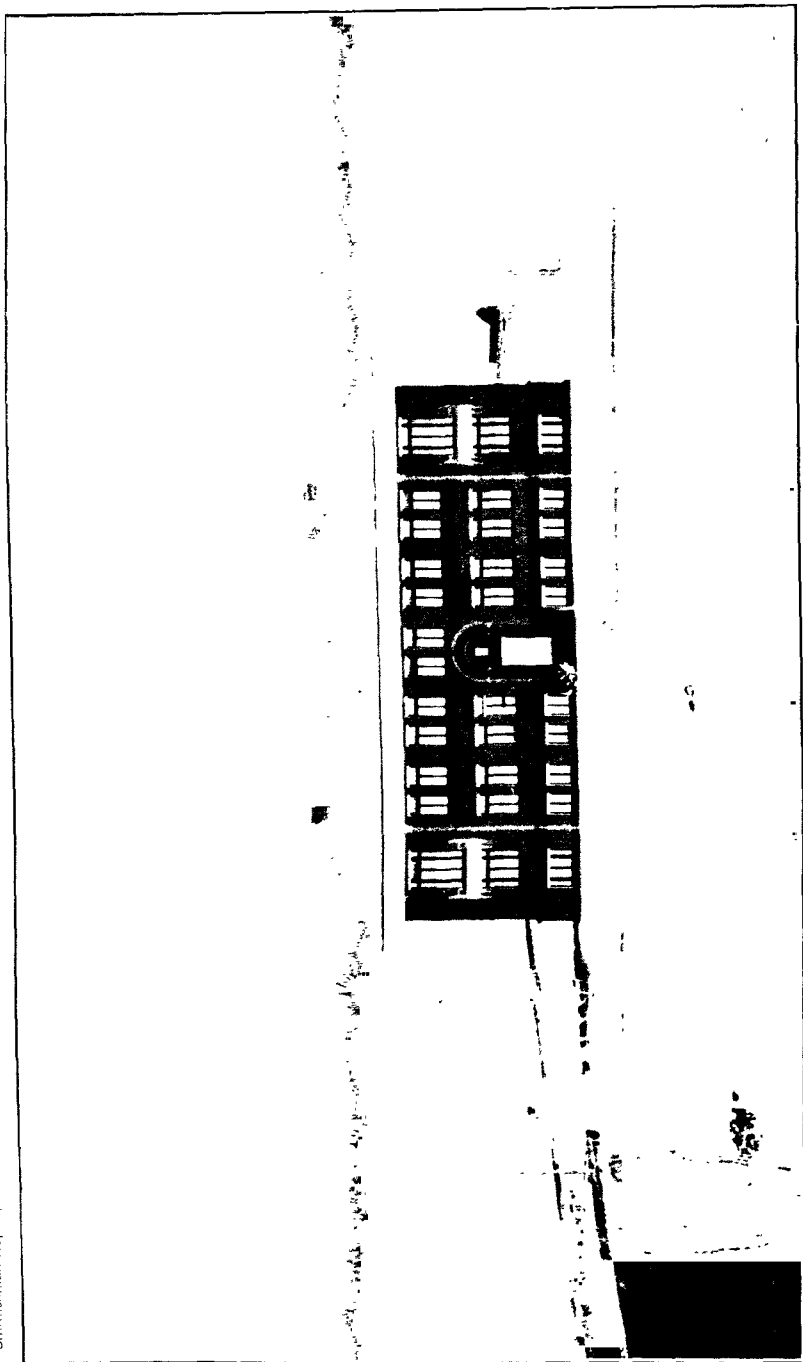
RESEARCH BUILDING, DEPARTMENT OF TERRESTRIAL MAGNETISM, CARNEGIE INSTITUTION OF WASHINGTON, D. C.

than that of the positive, or, in other words, the earth's total negative charge must be distributed through the larger sphere, and, if that be the whole earth itself, then for the chief term involved in the magnetic potential, the surface of the sphere containing the positive charge need be, on the average, only 0.4×10^{-8} cms., i. e. four-tenths of the radius of an ordinary molecule, below that of the earth's surface to give a magnetic field of the required strength. Taking the average atomic weight of the earth's substance in round numbers as 50, the mean volume density of either charge would be about 3.3×10^{12} electrostatic units.

At present there is little hope that a magnetic field, caused just as supposed, can be detected in the laboratory. For a sphere of 15 centimeters radius, rotating 100 times a second, the magnetic intensity at the poles would be but one hundred-millionth part (10^{-8}) of that of the earth. We thus see that the quantities involved in the solution of one of the great problems confronting the student of the earth's physics—the origin of the earth's magnetic field—may be of such a minute order as to be beyond the ken at present of the laboratory experimentalist. Perhaps the effects become appreciable in the case of the earth because of the fortunate fact that it is a body of sufficient size and angular velocity.

On the other hand, the geophysicist is at a great disadvantage in that he is unable to bring his earth-magnet into the laboratory and to experiment upon it—to reverse the direction of rotation, for example, and see what would happen! Fortunately for him, however, nature comes to his relief somewhat and performs experiments for him on his great magnet on a world-wide scale, by producing in an incredibly short time manifold and at times startling variations and fluctuations in the apparently fixed magnetization of the earth. Thus, on September 25, 1909, there occurred the most remarkable magnetic storm on record, during which, within a few minutes, the earth's magnetic movement, or intensity of magnetization, was altered by about one-twentieth to one-thirtieth part. The earth's magnetic condition was below par for fully three months thereafter. As this severe storm was accompanied by a brilliant display of polar lights, this is the most appropriate place to recall that Halley made the first suggestion of a connection between the aurora borealis and the earth's magnetism. (Pl. 8, fig. 1.)

It is firmly believed that a long step forward will have been taken toward the discovery of the origin of the earth's magnetism when once we have found out what causes it to vary in the surprising manner shown by the secular or long-period changes, by the magnetic storms, and the numerous other fluctuations, such as the diurnal variation, for example. The keynote of modern investigation in

terrestrial magnetism, as in the biological sciences, must surely be the study of the variations and mutations!

Is it not probable that the very features of the earth's magnetism regarded at one time as defects—the "constant inconstancies," as an early writer quaintly put it—will instead become sources of help and inspiration from totally different points of view or in some entirely different line of thought? Who knows of what import the riddles of the earth's magnetism, characterized by eminent physicists as being, next to gravity, the most puzzling of natural forces, may be, not simply to the magnetician alone, but to all interested in the steady progress of the physical sciences? Thus Schuster suggests that "atmospheric electricity and terrestrial magnetism, treated too long as isolated phenomena, may give us hints on hitherto unknown properties of matter." "The field of investigation into which we are introduced," says Maxwell, "by the study of terrestrial magnetism, is as profound as it is extensive." And, says Sabine, one of England's greatest and most enthusiastic magneticians, "Viewed in itself and its various relations, the magnetism of the earth can not be counted less than one of the most important branches of the physical history of the planet we inhabit."

MODERN IDEAS ON THE END OF THE WORLD.[1]

By Gustav Jaumann,

Professor of Physics at the Technical High School at Brünn.

We are totally ignorant of the beginning of the world. During the last century the hypothesis of Laplace and Kant that the planets proceeded from the sun and were cast off by the rotation of it enjoyed wide credence. According to this theory our earth was once in a state of glowing liquid. Judging by the increase in temperature in the deep strata, it is covered at the present time by the solidified crust, relatively very thin, on which we live. Such a conception has rendered plausible a belief in the deluge and in the idea of a final day of judgment when the world will be devoured by flames.

Geology, indeed, records horrible catastrophes: the highest mountains were formed by a single short earthquake of tremendous violence, the result of upheavals of granitic magma. By enormous volcanic eruptions erratic blocks were carried thousands of kilometers. In particular the whole of Asia suffered the invasion of the Indian Ocean, which was precipitated on the continent with inconceivable violence, sufficient to carry the rhinoceros and the mammoth, which are considered Indian animals, as far as the frozen fields of Siberia. Cuvier affirmed not only that the world would be destroyed some thousands of years hence, but that it has already many times undergone like cataclysms, each geologic formation constituting the burial place of a creation entirely separate in origin. According to this hypothesis, the termination of each geologic period has been marked by a complete ending of the world, and the opening of each succeeding period by a special creative act giving birth to a new fauna more perfect but equally incapable of evolution. By the side of the brilliant Cuvier lived, obscure and unknown, the much greater Lamarck. It is he who recognized the continuous evolution of the faunas in accordance with an immanent law, or at least in consequence of the capacity which organisms possess of perfecting them-

selves by assiduous exercise and by communicating in part to their descendants the improvements thus acquired. It is this way of thinking which, after a turn toward Darwinism,[1] has finally established itself. Now, to permit such an evolution of the organic world, from the beginnings to its actual perfection, requires a considerable duration of cosmic quiet. Geologic investigations since Lyell have indeed demonstrated that the passage from each geologic formation to that succeeding it is made gradually and without interruption. The inundations and volcanic catastrophes which are produced at all times, far from destroying worlds, have never been more than purely local. Volcanic eruptions are not the index of a fluid and incandescent nucleus, for the accumulations of liquid lava have little extension, so that even neighboring volcanoes, such as Vulcano and Stromboli, have no relation to each other. One can even affirm that the fluid incandescent nucleus of the earth does not exist. Recent physical observations, especially those relative to the transmission of the transverse seismical waves through the interior of the earth and to the period of migration of the terrestrial axis, admit of the conclusion that the earth in its entire mass is as elastic as a steel of good quality.

But now we must observe the very disquieting previsions of the exact sciences. These we must notice particularly, for physics and astronomy have exact natural laws, and in this way may be predicted in all probability the most distant consequences, for the laws which are concerned here, that of gravitation and that of the conservation of energy, are among the ones most firmly established.

The real achievement of Newton was to show that the law of gravitation had a more exact application than the laws of Kepler according to which the planets move along their elliptical orbits.[2] In reality the planets do not describe strictly elliptical trajectories. The form and the position of these trajectories change constantly, although with extreme slowness. The law of Newton affords an explanation of the greater part of these divergences, if the reciprocal

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[1] In this connection we designate as Darwinism only that part of Darwin's teachings which originated with himself; not the evolution theory, which is due for the most part to Lamarck, but rather the theory of selection, according to which there could not be any evolution of the organic world without the influence of selection in connection with the struggle for existence.

[2] The law of gravitation itself was not originated by Newton, but by Kepler, whose ideas exerted a powerful influence on Hooke, Halley, and Fermat. It was first formulated mathematically by Wren, whose physical work was otherwise unimportant. Newton only contributed proof of its correctness.

Kepler originated the fundamental and extraordinary new conception " Virtutem, quae planetas movet, residere in corpore Solis " (" The power which moves the planets resides in the mass of the sun "—heading of ch. 33 in Kepler's "Astronomia Nova." See " Jo. Kepleri Opera Omnia," Frisch's edition, vol. 3, p. 300). He also originated the idea of the field of gravitation, in which the force diminishes with the distance from the sun, and the idea of universal gravitation. Had Galileo's dynamics controlled Kepler as it did Huyghens, he would not have needed half his genius to have anticipated Newton's contributions to the subject.

attractions of the planets are taken into consideration. Taking these deviations into consideration, it is possible at present to calculate to within a few seconds the positions of the sun, the moon, and the planets a hundred years in advance. But to determine at a distance of millions of years the end of the Newtonian world enormous mathematical difficulties must be overcome; indeed, it is a matter concerning the problem of the stability of the planetary system and of calculating whether the disturbing influences, weak but incessant, which the planets exercise upon each other will nearly counteract each other in time or will end by entailing the destruction of the planetary system.

Eminent scholars have always taxed themselves with resolving this fundamental problem relative to the stability of the world. Laplace and Lagrange showed, by means of an approximate calculation, that the planetary system of Newton appeared to be stable. Poisson demonstrated that by further refining the calculation later epochs could be surveyed, in which greater and greater fluctuations in the form of the planetary orbits were present. Finally Poincaré proved that by carrying the calculation to its limit, a future time was disclosed in which the planets would experience unlimited, progressive, so-called secular disturbances and, finally, some of them would fall into the sun, and others lose themselves in the cold of cosmic space. Thus, the planetary system of Newton has no stability, no internal constancy. But the foregoing calculations were made on much too favorable a basis. Cosmic space can not be empty, as Newton held. Since it can transmit light, it must be filled with a medium, extremely tenuous and cold, called cosmic ether. The extreme vacuum obtained in the laboratory, cooled to $-170°$ C., presents a considerable viscosity, which is only ten times inferior to that of the normal air.[1] Consequently, the cosmic ether must oppose to the movement of the planets a very appreciable frictional resistance. They must continually lose energy of motion; in addition to which, the attractive action of the sun becoming more and more considerable, the planets should describe orbits more and more narrow and should end, in some millions of years, by precipitating themselves into it. Thus, again, we have the "igneous" death of the earth. But that end would be preceded by the destruction of the terrestrial organisms, all being menaced by death from the cold, which would set in much earlier.

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[1] This extreme vacuum at $-170°$ C. has the modulus of viscosity 2×10^{-5} c. g. s. To overcome the resistance that the ether offers to our earth would require more than 150,000,000 horsepower. Meteorites must glow in the ether if their diameter be less than 50 cm. As a matter of fact, a glowing meteorite has been observed at a height of some 780 kilometers (above Sinope on Sept. 5, 1868, reported by G. von Niessl in Verhandl. d. naturforsch. Vereines in Brünn, vol. 17, p. 316, 1879), and even in the spectrum of the comets when approaching perihelium (when their velocity is greatest) clear indications of the glowing of solid bodies have been observed.

The energy thrown out with the sunlight is several billion times greater than the total interchange of energy which takes place on the earth. The sun gives off continually enormous quantities of it, and its supply, of whatever unknown kind it may be, must finally be exhausted. It would cool down more and more, and our civilization, after terrible struggles, would meet with disaster more and more amidst the ever-present ice.

Thus the two fundamental physical laws lead, it is seen, to essentially gloomy consequences, but, with all the respect that is due to their sublime results and to their precision, it is only right to ask whether they are really established with such ideal exactness as to enable one to draw conclusions applicable to epochs immensely remote, and to comprehend the very plan of creation. Before accepting these consequences, it will be well to submit these inexorable laws to a much more searching scrutiny. That the law of gravitation will not support an examination carried to extreme limits, nearly all astronomers agree in admitting. The most striking deviation from this law is offered us by the moon, which undergoes an inexplicable acceleration, not less than 6 seconds per century. An analogous anomaly, more marked and still more complicated, has also been recognized in the motion of Encke's comet. The orbit of Mercury presents an inexplicable perihelic rotation, attaining 40 seconds per century, and its eccentricity is not augmented with the rapidity which the law of gravitation demands. The orbit of Mars is subject to anomalies of the same nature, while the inclination of the orbit of Venus increases too rapidly by 10 seconds every century. Terrestrial gravity presents, even from the point of view of direction, a diurnal and annual oscillation of a fraction of a second, which is not to be explained alone by the attraction of the moon or of the sun.[1] It is true that these are relatively small and isolated deviations, and that in general the law of gravitation suffices for the calculation of the motions of the stars with a sufficient approximation, always assuming that the cosmic ether is absolutely devoid of friction. This latter, however, is far from being accepted by physicists. When one considers that the periodic comets, even the smallest ones, apparently undergo no frictional resistance, that they are capable of penetrating the solar corona at a speed of 5,500 kilometers per second, without undergoing appreciable loss, one is obliged to admit that the law of gravitation is not sufficient, but that forces unknown, though hinted at by Kepler, act upon the stars in motion, and tend to offset the effects due to friction of the cosmic ether. It is a fact that no trace, however slight, of a beginning of the falling of the planets toward the sun, as the law of Newton predicts, has yet been shown. The same

[1] G. H. Darwin, Tides, 1898, p. 125; O. Hecker, Publications of the Royal Prussian Geodetic Institute, No. 32, 1907.

may be said of the cooling of the sun, which should follow in accordance with the law of energy. It was supposed for a long time to be self-evident that the climate of the earth had grown constantly cooler, but this idea has been entirely abandoned. Fluctuations less than 10 degrees centigrade on both sides of the mean temperature have often occurred, several times in Europe, thus placing these regions now under tropical conditions, and now under the conditions of the Arctic Zone. But from this point of view the most remote ages of the geologic history of the earth differ not at all from the present epoch. Glacial formations, extensive but not thick, have been found in early Cambrian strata.[1] At that time the temperature was not higher but lower than in our epoch, and more than a hundred million years have passed since then.

One can with difficulty admit of the existence in the sun of a supply of energy able to endure without appreciable decrease, for so long a time, the enormous expenditure due to radiation. The stability of the planetary system and the inexhaustible luminous power of the sun are, furthermore, to a certain extent verified by direct geologic observation.

How is it that the law of gravitation and the principle of the conservation of energy fail so entirely in their prophecy concerning the end of the world? What is the hidden defect of these laws which, as the foundations of physics, have given such magnificent results within narrower limits, and how can they be given an entirely correct form?

Regarding these really fundamental questions of theoretical physics, I feel myself called upon to speak, in so far as they fall within the field of my own studies. I should point out, however, that questions are concerned which are far from being decided, and that I can treat here only their " phenomenalistic " aspect. The Newtonian hypothesis of the attraction of a star on a remote body, directly and instantly, without the physical intervention of an intermediary medium, was an abstraction nearly accurate, though at bottom little true to nature. Laplace himself admitted the progressive transmission of gravitation.[2] He supposed that this effect was propagated, though at great speed, through the cosmic ether. The magnetic forces between two magnets were likewise supposed at first to act immediately at a distance. Faraday recognized eventually that the air or similar medium contained between the two magnets (the magnetic field), far from being indifferent, was in a state of tension, and that the magnetic effects of one magnet on another were propagated from point to point, from one particle to the particle immediately adjoining it. It is thus that the elementary action

[1] Compare, for example, Walther, History of the Earth, 1908, p. 199.
[2] Laplace Mécanique cóleste. vol. 4, p. 317.

is always produced in ultimate particles situated in the magnetic field, and its law is a differential law expressing the relation of cause and effect between the existing conditions and their causative predecessors in each ultimate particle of the space. It is from the interaction between all the ultimate particles of the magnetic field in the so-called integral that the effects at a distance result. Maxwell established the laws of effect from point to point of electromagnetism (or differential laws of the electromagnetic field), which with an admirable simplicity not only explained the electromagnetic phenomena formerly known (which the laws of effect at a distance were equally capable of doing), but did much more; they predicted, indeed, the propagation of electric vibrations through space in the form of electromagnetic rays. The luminous rays appeared thus as electromagnatic rays. Hertz obtained, with purely electromagnetic resources, electromagnetic rays of great wave length, and Marconi has utilized these same rays in wireless telegraphy. Thus it is that one of the greatest and most difficult advances in the theory, the transition from laws of effect at a distance to theories of effect from point to point, led immediately to a great technical advance.

At that time (more than 20 years ago), many physicists, Hertz and Mach in particular, recognized that the real object of the theory was to explain physical phenomena by differential laws, a task which seemed to pass much beyond the attainable, but it has been in large part satisfactorily performed,[1] since at present the law of gravitation itself can be expressed in the form of a law of effect from point to point.[2] The end sought in this connection consists in dethroning the old corpuscular and mechanical theories still so full of vigor. The list of facts brought forth by the two contending parties increases in length from year to year and the struggle between phenomenalistic investigation and mechanical investigation is waged on a field of great extent, embracing almost the entire domain of the exact sciences. The combat centers around the question of the nature of light and of the cathode rays.[3] The new theory of gravitation is only a partial victory

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[1] G. Jaumann. A complete system of physical and chemical differential laws, Sitzungsber. K. Akad. Wiss. Wien, Math.-Naturwiss. Kl., vol. 120, pt. 2a, 1911, pp. 385–530.

[2] G. Jaumann. The theory of gravitation, Sitzungsber. K. Akad. Wiss. Wien, Math.-Naturwiss. Kl., vol. 121, pt. 2a, 1912, pp. 95–182.

[3] The majority of physicists still subscribe to the emission theory of cathode rays (the corpuscular or emissional theory) and there is a tendency, under the leadership of Einstein and Planck, toward giving up finally the essential features of the classical theory and going back to a sort of emission theory of light.

Regarding the undulation theory of cathode rays and the phenomalistic undulation theory of light in dispersion media, see G. Jaumann, The electromagnetic theory (Sitzungsber. K. Akad. Wiss. Wien, Math.-Naturwiss. Kl., vol. 117. pt. 2a. 1908, pp. 379–543), which paper was rejected by the editors of the Annalen der Physik in 1908 and in 1911 was honored by a prize by the Imperial Academy of Sciences in Vienna. See also E. Lohr, The boundary conditions in G. Jaumann's electromagnetic theory (Sitzungsber. K. Akad. Wiss. Wien, Math.-Naturwiss. Kl., vol. 120, pt. 2a, 1911, pp. 1503–1567, and vol. 121, 1912. pp. 633–678.

on the extreme wing, but by virtue of it we now have exact notions regarding the manner of propagation of gravitation through the cosmic ether. The anomalies of the field of gravitation compensate each other in cosmic space, according to a law analogous to that which rules the irregularities of the distribution of temperature in a good conductor of heat. It is only for stars in a state of repose that the Newtonian law of effects at a distance follows exactly from the differential law of gravitation.

Now, the motions of the planets produce disturbances, a kind of damming up, so to speak, of the field of gravitation in front of the moving stars, giving birth to new forces of gravitation added to the Newtonian forces. Although very small, it can be determined with precision that the most important among them has the same direction as that of the motion of the planet to which it is a stimulus. It increases with the speed of the planet and varies in inverse ratio to the distance separating it from the sun. These new forces of gravitation introduce into the planetary movements disturbances which can be calculated without difficulty, and even cause the deviations from the Newtonian law which we have mentioned above. By them are explained the anomalous perihelic rotations, accelerations, oscillations of the vertical, etc.—that is, all the phenomena of gravitation, without any being left over, which the Newtonian law of effects at a distance was incapable of doing. These new forces of gravitation moreover give to the planetary system a physical stability of unlimited duration. They keep the planetary orbits in their present form, not only in spite of the very considerable resistance due to friction of the cosmic ether, but also in spite of enormous accidental disturbances. If a disturbance of this nature (which might be due, for example, to the passage in the neighborhood of the solar system of a fixed star imbued with a very rapid motion of its own) should be produced, and modify entirely the form of the planetary orbits, the new forces of gravitation would introduce into the elements of the orbits such variations that these planetary orbits would gradually return exactly to their existing stable form. Far from becoming dangerous, the frictional resistance of the cosmic ether, on the contrary, helps essentially to make the planetary orbits stable. The greater this resistance the more considerable become the new forces of gravitation and the more obstinate the planetary orbits in conserving, in spite of all the disturbances, their stable form. Thus there can no longer be any question of the planets dropping into the sun. Far from being unstable, far from tending toward a destruction more or less remote, the planetary system is, then, established for a duration which, estimated according to the ideas of time that we are able to conceive, may be considered as eternal.

The absolute validity of the principle of the conservation of energy is incontestable, but its new differential form [1] leads in entirely new directions. The cause of the indefinite constancy of the temperature of the sun rises from the inevitable reaction of the differential law of gravitation on the law of the propagation or radiation of energy and in particular the differential law of the conduction of heat, established by Fourier. The forms of the two differential laws must be placed in opposition to each other in order, when taken together, to correspond to the principle of energy. The very considerable rôle which the mass of bodies plays as the cause of the concentration of the forces of gravitation demands a corresponding influence of the mass of bodies on the concentration of energy. To the radiation of energy called the flow of heat there corresponds a new flow of energy in the direction of gravitation. Thus the law of the conduction of heat established by Fourier is strictly applicable only to media of extremely slight density. In dense substances there must be a hitherto unrecognized concentration of energy, and this is not an hypothesis, but simply the balance of the system of laws of effects from point to point. All dense bodies should in consequence produce heat incessantly and spontaneously. All bodies are so many radiators functioning without loss, although in very different and to us generally imperceptible degrees. Far from being in contradiction to the principle of energy, this fact springs exactly from its expression in the form of the law of effect from point to point. The salts of radium, indeed, produce a similar effect of spontaneous radiation, but this is of such an exceptional intensity that it has amazed the physicists. Upon its discovery doubts were conceived of the validity of the principle of energy, but it is only the integral form of the principle which gives place to these doubts, while the differential form, or the law of effect from point to point, is thus all the more firmly established. The increase of temperature in the deep strata of the earth is explained by this effect of spontaneous radiation without the intervention of the hypothesis of deposits of radium. Moreover, there is produced toward the sun an enormous concentration of the new radiation of energy arising from the field of gravitation, which compensates for the loss of energy which the sun undergoes and assures the permanent constancy of its mean temperature. Consequently the sun yields no energy at all to the wide circle of cosmic space; that which it radiates into cosmic space is recovered in the form of this flow of energy from the field of gravitation. The senseless waste of the sun's energy, of which the theory of effects at a distance seems to

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[1] G. Jaumann, Sitzungsber. K. Akad. Wiss., Wien. Math.-Naturwiss. Kl., vol. 117, pt. 2a, p. 388 et seq. ; vol. 120, p. 398 and p. 505 ; vol. 121, p. 169.

prove the existence, is shown by the theory of effect from point to point to have no place in nature. A cooling off of the sun will not bring the development of our civilization to a stop, after which, through the deterioration of the climate, it will disappear and the last men will live like Eskimos on the entirely glaciated earth. The radiation from the sun being stable, the intellectual and physical evolution of humanity will be able for an immeasurable time to mount to heights surpassing, perhaps, anything the imagination is capable of conceiving.

Thus, as a result of the development of the differential theories, a new and unsought contribution to cosmology of high and moral value has been obtained.

RECENT DEVELOPMENTS IN ELECTROMAGNETISM.[1]

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The domain of electromagnetism is to-day so broad and so complex that in a few pages we can not hope to show all its frontiers. For the present, therefore, we will limit ourselves to reviewing certain problems which particularly attract our attention, either by the number or the importance of the investigations which they have produced. We will start with the theoretical developments and end with the results gained in the laboratory.[2]

I. THE DYNAMICS OF THE ELECTRON AND ELECTROMAGNETIC MASS.

The electromagnetic theory of matter and the ether in the perfected form due to H. A. Lorentz is really a theory of electrons. Matter in all its forms is by it considered as made up of complex groups of which an essential element is the negative electron either free or bound to an atom. This element is defined by its charge e (4.5×10^{-10} electrostatic units) and its mass, which is invariably at small velocities ($e/m = 1.76 \times 10^7$ electromagnetic units). This result was the logical consequence of a long and brilliant series of discoveries which marked the end of the last and the beginning of the present century (cathode rays, X rays, gaseous ions, Zeeman effect, radioactivity, etc.).

A fundamental problem of this theory is evidently the study of the motion of an isolated electron and the electromagnetic perturbations which accompany it. This problem gains in interest as experimental demonstration becomes possible. Cathode rays from all sources (rays from Crookes's tubes, from the photoelectric effect, the β rays from radium) are, indeed, fluxes of electrons projected at great velocities from matter. Let us, therefore, review first the important results of the theory which was developed by Heaviside

and Searle and later and fundamentally by J. J. Thomson (1881), a theory which has passed through many successive developments.[1]

(1) An electron moving with a uniform velocity, or at least a velocity only slowly variable (quasi-stationary), carries invariably tied to it an electromagnetic field the form of which can be completely deduced from the Maxwell-Lorentz equations. This moving field has been called the "velocity wave."

(2) If the electron suffers an acceleration, a wave is immediately propagated from it having all the characteristics of a luminous wave (transverse vibrations, rectangular electric and magnetic fields). This disturbance has been called an "acceleration wave." At great distances from the electron the latter wave alone exists because its amplitude varies inversely as the distance from the electron and not as the inverse square as does that of the other wave. This shows us the probable origin of luminous radiations and the root of the explanation of the Zeeman effect. Here also we find the explanation of X-rays which are electromagnetic pulses[2] due to the abrupt stoppage of cathode corpuscles at the anticathode and the resulting negative acceleration.

(3) In order to give an electron a quasi-stationary movement there must be communicated to it energy which is stored up in its field as electric and magnetic energy. The necessary calculations for this field are relatively simple where the ratio (β) of the velocity (v) of the particle to the velocity of light, V) is small. They become more complicated where β approaches unity and were first made completely by Max Abraham[3] in 1903 upon the hypothesis of a rigid, spherical electron carrying a charge uniformly distributed throughout its volume. Then the magnetic energy of the field can always be expressed in the form of kinetic energy, $\frac{mv^2}{2}$. It is quite natural to speak of the coefficient m as the electromagnetic mass of the electron. This mass may be superposed upon the ordinary mass, at least it does not wholly take its place. This leads to an electromagnetic interpretation of mechanics. In this new mechanics, the mass m does not maintain a constant value m_0 except at very small velocities. For a velocity comparable with that of light (β near 1) the mass becomes a function of β and increases indefinitely as β approaches unity. Further it is necessary to distinguish between a longitudinal and a transverse mass according

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[1] See the references cited further on.

[2] We have not sufficient space to describe the curious theory of Bragg according to which the X-rays and the γ rays of radium are uncharged particles of matter. Moreover this theory appears to be contradicted by the recent beautiful experiments of Lane and his pupils upon the diffraction of X-rays by crystals. (Bragg, Phil. Mag., Oct., 1907; Chem. News, vol. 97, p. 162, 1908; Radium, p. 213, 1908. See also articles by Brunet in this Revue for Feb. 15, 1913.)

[3] See Ions, electrons and corpuscles, vol. 1.

to the orientation of the accelleration with regard to the velocity. The transverse mass, detectable only in the experiments with the deviations of the cathode rays, is given according to Max Abraham by the relation

$$\frac{m}{m_o} = \frac{3}{4\beta^2}\{\frac{1+\beta^2}{2\beta} L\frac{1+\beta}{1-\beta} - 1\}$$

This formula seemed completely verified by the observations of Kaufmann [1] (1900 and 1903). He measured the variation of the ratio e/m with the velocity for the β rays from radium, utilizing the electric and magnetic deviations of the electrons having velocities reaching ninety-five one-hundredths of the velocity of light.

Since then other formulæ have been proposed in the place of this. Langevin and Bucherer,[2] basing their formula upon the hypothesis of a deformable electron of constant volume, obtained

$$\frac{m}{m_o} = (1-\beta^2)^{-\frac{1}{3}}$$

Further, as a consequence of the development of the theory of relativity (see Sec. II of this article), H. A. Lorentz, postulating an electron of constant equatorial diameter, deduced a third formula:

$$\frac{m}{m_o} = (1-\beta^2)^{-\frac{1}{2}}$$

These new formulæ also appear to fit the experiments of Kaufmann. It became necessary, therefore, to make new experiments more precise than those of Kaufmann in order to choose between the various formulæ. Several attempts to do this have been made.

Bucherer [3] placed a grain of radium fluoride at the center of a condenser formed of two flat disks 8 cm. in diameter and separated by 0.25 mm. This condenser was inclosed in an air-tight cylindrical box, the walls of which carried a photographic film. This was all placed in a uniform magnetic field parallel to the plates and a very perfect vacuum produced. When the condenser is charged, the β rays trace upon the film a line the analysis of which permits the calculation of the variation of e/m with the velocity. In this case the formula of Lorentz is found to fit best, confirming nicely the principle of relativity.

[1] See Ions, electrons and corpuscles, vol. 1.
[2] Langevin, Revue générale des Sciences, p. 267, 1905.
[3] Bucherer, Physik. Zeitschrift, vol. 9, p. 755, 1908; Annalen der Physik, vol. 28, p. 513, 1909.

These conclusions have been clenched by yet later experiments. Hupka[1] used the electrons from the photo-electric effect, produced in a very perfect vacuum and accelerated by intense electric fields reaching a strength of 90,000 volts. The knowledge of the velocity v and the ratio e/m was deduced from the magnetic deviation, rendered evident by a fluorescent screen, and the magnitude of the accelerating potential. The maximum velocities obtained were of the order of $v/2$. The formula of Lorentz fits these observations also better than that of Abraham. However, these experiments are less convincing than the preceding ones, as Heil noted,[2] since the highest potentials must be known with a precision greater than 1 per cent, an accuracy difficult to obtain.

C. E. Guye and Ratnovsky,[3] desirous of escaping this difficulty, used ordinary cathode rays, produced in a good vacuum, and deviated at the same time both electrically and magnetically so as to get rid of the necessity of measuring the potential used. These results also confirm Lorentz's formula at the expense of Abraham's.

We are led by all these results to look upon an electron as deformable only in the direction of its motion, conformable with the principle of relativity; in this respect they undergo the contraction of Lorentz (see further on). Do all difficulties now disappear? Without considering the objections of a more general nature which are to-day urged against the principle of relatively (see Sec. II), we must say, no. As H. Poincaré[4] has observed, we can not comprehend why an electron does not disintegrate spontaneously under the influence of the electric and magnetic forces due to its charge unless there comes into play, in order to maintain equilibrium, other forces from without analogous to pressure. We are led thus to introduce something further than pure electromagnetism as a basis of our new mechanics. We are just as far as ever from comprehending the primordial forces underlying matter.

II. THE PRINCIPLE OF RELATIVITY.

Lorentz has shown that the electromagnetic theory furnishes an explanation of the negative results of the experiments which were expected to demonstrate, either by electrical or optical means, the movement of translation of the earth relative to the supposed stationary ether. These experiments could detect only the effects of the first order with reference to β (quotient of the velocity of translation of the earth, v, relative to the velocity of light, V), while

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[1] Hupka, Verh. der Deutsch. Phys. Gesellsch., vol. 11, p. 249, 1909 ; Annalen der Physik, 1910.

[2] Heil, Annalen der Physik, vol. 31, p. 519, 1910.

[3] Guye and Ratnovsky, Comptes Rendus, CL, p. 326, 1910.

[4] H. Poincaré, Rendiconti del Circolo Math. di Palermo, vol. 21, p. 129, 1906.

theory shows that the effects should be of the order of β^2 or smaller. This theory then received a rude shock from the celebrated experiment of Michelson (1881) relative to the interference of two rays propagated at right angles to each other and which should show the terms of the second order of β. The negative result was irreconcilable with the theory, the effect observed being less than one one-hundredth of that calculated.[1] We must therefore modify the theory.

The modification necessary was announced almost at the same time by Lorentz and by Fitzgerald. It consisted in supposing that a moving solid body suffers a contraction in the direction of its motion equal to $\beta^2/2$. This is the celebrated hypothesis known as the "contraction of Lorentz." It seems very strange at first sight and instigated the experiments by Lord Rayleigh,[2] and by Brace,[3] who tried to find evidence of this contraction in the double refraction which it should produce. Their results were negative. In order to explain these consequences and place the theory in a more satisfactory form, Lorentz was led to a hypothesis which contained the germ of the theory of relativity.[4] He showed that the electromagnetic equations for bodies in motion could be put in the same form as for bodies at rest by means of what is called the "transformation of Lorentz." This permits the expression of the coordinates x, y, z, and the time t for a system in motion as a function of the coordinates x_0, y_0, z_0, and t_0 for the system at rest, thus establishing a correspondence between the electric and magnetic fields of the two systems. This group of transformations contains, as a particular case, the hypothesis of contraction, which is found to be of the magnitude $(1-\beta^2)^{\frac{1}{2}}$, in agreement almost to terms of the fourth order with the magnitude originally admitted. It further explains the negative results of Michelson, Rayleigh, and Brace. Through it we understand the negative results of Trouton and Noble in their electrostatic experiment which was expected to indicate the terms in β^2.[5]

The experiments explained by the transformation of Lorentz go only to the terms in β^2. We do not know any at present which go further, but it is natural to suppose that even taking into account terms of higher orders, we will never be able to get evidence of the motion of translation of the earth with reference to the ether. In other words, we can probably detect only the relative motions of two material systems with reference to each other and not their absolute

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[1] The original experiment was made by Michelson and Morley in 1887 and repeated most recently by Morley and Müller. Phil. Mag., vol. 9, p. 680, 1905.

[2] Rayleigh, Phil. Mag., vol. 4, p. 678, 1902.

[3] Brace, Phil. Mag., vol. 7, p. 317, 1904.

[4] See the admirable book by Lorentz, entitled "The Theory of Electrons," and published by Teubner in Leipzig, 1909.

[5] Trouton and Noble, Phil. Trans., vol. 202, p. 165, 1903. See also Langevin, Comptes Rendus, vol. 140, p. 1171, 1905.

movement with reference to a supposed stationary ether. This novel hypothesis was announced in its most general form for the first time by Einstein,[1] who named it the principle of relativity. Starting with this simple principle, Einstein modified slightly the transformation of Lorentz, giving to it a physical basis of very great generality and gathering all the conclusions resulting from it into a group of perfectly consistent formulæ.

We will not state here all the physical and philosophical consequences of this theory of relativity. We will note only the absolute character assumed by the two fundamental postulates of this theory: First, the ether is immovable and penetrates matter perfectly; second, the velocity of light is an absolute invariant and represents a superior limit which no other velocity can exceed (whether for matter in motion or the propagation of waves). The theory has been further developed (principally by Germans) by Einstein (1905–1912), Minkowski (1905–1908), Planck (1907–8), Born (1909), Sommerfeld (1910), Laue (1911), etc. The various points of view which these physicists have adopted are too numerous to be given here in detail; some have tried to put the transformations of Lorentz into more geometrical and comprehensive form (Minkowski); others have deduced the kinetic consequences of the principle, either for a moving point (composition of velocities according to Sommerfeld) or for a solid body in rotation (Born, Laue, etc.). Difficulties and complications quickly arise as soon as the motion of uniform translation originally supposed is departed from and these difficulties have not yet been overcome. The total absence of any experimental basis or confirmation of these later developments deters us from further discussion. We will stop a moment only on one of the most paradoxical consequences of the principle of relativity which will bring out the difficulties which the theory encounters and rebut the absolutism of the principles which it uses as bases of the physical sciences. At the start Einstein[2] showed that if the energy of a system increases by the amount E, *the principle of relativity requires that its mass increases at the same time by E/V^2*. Only on this condition can the principle of the conservation of the movement of the center of gravity as well as the new system of mechanics be maintained. Accordingly, mass and energy are not really distinct; the principle of the conservation of mass is inseparable from the principle of conservation of energy. This result, however strange, is nevertheless consistent in itself.

Einstein himself, basing his deductions on this consequence, tried to bring back to the principle of relativity the absolute value which

[1] Einstein, Annalen der Physik, vol. 17, p. 902, 1906.

[2] Einstein, l. c. and Annalen der Physik, vol. 20, p. 627, 1906; vol. 23, p. 378, 1907, etc.

had been attributed to it since 1905.[1]   He has tried to include in the electromagnetic synthesis of the universe the phenomenon of gravity, hitherto so rebellious against all our efforts at explanation. He noted that a uniform gravitational field of constant acceleration, γ, is equivalent to a medium free from gravitation in which the reference axes are supposed acting with a uniform acceleration $-\gamma$. Next we must generalize the principle of relativity and pass from the case considered until now of a uniform velocity of translation to that of a uniform acceleration. In the earlier case we were led to attribute to energy a mass $m=E/V^2$; now, if we wish to preserve the principle in its entirety we must attribute to the same energy the weight $m\gamma$. As a particular case, radiant energy, light, must have weight; a beam of light must then be deviated by the masses close to which it may pass. Einstein's calculation showed, for example, that the angular distance between a star and the center of the sun must be decreased by about one second when the star appears close to the sun. The measurement could be attempted at a total eclipse of the sun.

There is no need of calling attention to the strangeness of these conclusions. The important thing from a philosophical point of view is that we are obliged to give up the absolute invariability of the velocity of light, V, considered at the start as an unassailable axiom. This invariability is only true in a system where the gravitational potential δ remains constant. For variable potentials the velocity of light must vary according to the formula, $V=V_0$ $(1+\Phi/V^2)$. So it is only in the case of uniform motion of translation that the transformation of Lorentz represents the phenomena of a system in movement. In the more general case the group of transformations is more complicated and as yet undetermined; the equations to be substituted for those of the classic electromagnetism are also undetermined.

This new point of view of Einstein has at least one incontestable utility: It makes us realize that the postulates which were at the basis of the earlier principle of relativity (the invariability of V, etc.) are perhaps only approximate affirmations, susceptible of modification, and not first truths. It has led us from metaphysics to physics. And since the discussion became opened anew concerning the foundations proposed by Einstein we will not be surprised to find that Max Abraham, adopting this new conception of mass and weight, has developed a new theory of gravitation, different in many respects from that of Einstein. Abraham[2] renounces the generaliza-

[1] Einstein, Jahrbuch der Rad. and Electronik, vol. 4, p. 4; Annalen der Physik, vol. 35, p. 898, 1911, etc.

[2] Max Abraham, Phys. Zeitschr., vol. 13, No. 1, 1912; Annalen der Physik, vol. 38, p. 1056, vol. 39, p. 444, 1912; Nuovo Cimento, January, 1913.

tion of the principle of relativity in the case of acceleration. Then considering that as a whole the principle of relativity has failed, he keeps the Lorentz transformation only for very small changes in the variables. Considerable discussion has passed between him and Einstein, but we will not follow the details.[1]

Admitting that these theories will have a lasting effect upon science, in the future new experiments will be required and a more powerful theoretical effort than that of the past. We will close our exposition of this question by citing the opinions of several skeptical physicists who, from the beginning, have found the postulates upon which the theory of relativity rests too absolute and to whose voices we are now beginning to listen.

The ether in the principle of relativity has been emptied little by little of all its physical properties; it is represented now only by a system of mathematical equations, those of Maxwell-Lorentz, and a number, the velocity of light. It remains as the vehicle of radiant energy without our questioning how. Ritz,[2] following to the logical conclusions such notions, proposes to renounce wholly the hypothesis of an ether and to return to a theory very close to the old one of emission. According to him, we need not speak of electric and magnetic fields, but only of electric charges acting upon each other. We thus return to action at a distance but taking into account the finite velocity with which such action takes place. Consequently it is necessary to throw away the partial differential equations of the electric field and replace them with integrals (retarded potentials). There is thus introduced an irreversibility of which the former equations could not take account. Mass at great velocities will remain constant, but the force will vary. We thus arrive at another system of mechanics. Against these new conceptions, the development of which was unfortunately interrupted by the death of the author, there are grave objections which have so far kept the majority of theorists from adopting them, although they are perfectly consistent among themselves. .

Brillouin,[3] on the other hand, makes the ether more substantial than has been customary. There must be, according to him, a drastic revision of the hypotheses relative to it. For example, its absolute immobility, perfect permeability, homogeneity, isotropy, and the invariability of the velocity of light. Those upholding the principle of relativity have themselves commenced to attack the last postulate, as we have just seen. Now it will be the turn of the other properties. We may come, through the increasing acuteness of our powers of

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[1] Einstein, Annalen der Physik, vol. 38, p. 355 and 1059, 1912; vol. 39, p. 704, 1912.

[2] Ritz, Annales de chimie et de physique, vol. 13, p. 145, 1908.

[3] Brillouin, Scientia, vol. 13, p. 10, 1913. See the Revue générale des Sciences, Mar. 30, 1913, p. 214.

analysis, to admit, to a closer degree of approximation, that the ether, at least slightly, is similar to ordinary matter, that it may propagate a disturbance with a velocity greater than that of light, that it does not remain perfectly stationary when matter traverses it, etc. New experiments must be added to the purely electro-optic ones of Michelson, Rayleigh, Brace. and Troughton before we will be able to build these theories.

III. ELECTROMAGNETISM AND RADIATION.

The difficulties just described are not the only ones which the modern theory of electromagnetism encounters. Perhaps the gravest ones arise in adapting it to the experimental facts of radiation. We know that thermal radiation in equilibrium in a constant-temperature chamber, and called " black radiation," has a density independent of the particular body producing it. It is a function only of the wavelength λ. and the absolute temperature T. Our theoretical knowledge of this density. u_λ, is expressed by the well-known laws of Kirchoff. Stefan-Boltzmann, and Wien.[1] Our experimental knowledge is expressed by the formula of Planck,

$$u_\lambda = c_1 \lambda^{-5} \left\{ e^{\frac{c_2}{\lambda T}} - 1 \right\}^{-1}$$

This equation satisfies not only the three theoretical laws but also corresponds to the observed distribution of energy in the spectrum of a black body. This formula reduces for large values of λT to the earlier one of Rayleigh,

$$u_\lambda = c_1 / c_2 \cdot T / \lambda^4.$$

Now, the electromagnetic theory seems to lead almost inevitably to Rayleigh's formula for *all wave-lengths* in flagrant contradiction to experimental facts. The second formula. indeed. does not give a maximum to the radiation distribution curve and makes the total radiation *infinite*. This consequence. which the researches of Lord Rayleigh[2] and Jeans[3] made extremely probable. has been rendered certain by those of Lorentz.[4] According to the latter's re-

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[1] These laws rest only on the Doppler-Fizeau principle. thermodynamical reasoning and the pressure of radiation, principles which may be held as well proven if not as experimental facts.

[2] Rayleigh, Phil. Mag., vol. 2, p. 539. 1900.

[3] Jeans, l. c., vol. 10, p. 91, 1905 ; vol. 17, p. 229, 1909 : vol. 17, p. 773, 1909 ; vol. 18, p. 209, 1909.

[4] Lorentz, Revue générale des Sciences, p. 14, 1909 : La théorie du rayonnement (The theory of radiation). Rapports au Congrès de Bruxelles de 1911, publiés par Langevin and de Broglie.

searches, the most general equation of an electromagnetic system, based upon the ether, electrons, and matter, by a suitable choice of parameters can be reduced to the Hamiltonian form of the equations of mechanics. The application of the methods of probability and statistical mechanics, especially the theorem of Liouville (which is a consequence of the Hamiltonian form), leads us, then, to consider as applicable to the ether the theorem of the equipartition of energy which also brings us out with Rayleigh's formula.

In order to escape from this blind alley and obtain the earlier formula, Planck invented the hypothesis of the discontinuity of energy or quanta.[1] According to this hypothesis, the molecular resonators can not exchange energy with the surrounding medium except in whole multiples of the same elementary quantity (quantum), $h\gamma$, an amount proportional to the frequency of the resonator. The constant h would be a universal constant. We will not explain here the various forms given to the theory by Planck himself, Sommerfeld, Einstein, H. Poincaré, and others (see articles cited, note 4, p. 231). We will pass over all the consequences which have been deduced from this hypothesis (theory of specific heats by Einstein, etc.), except those which are purely electromagnetic.[2]

It appears that we need not give up for the free ether the equations and ordinary laws of electromagnetics or the dynamics of the free electron. The modification of the electromagnetic theory which we must make, if necessary, relates only to the relations between matter and the ether; that is to say, with regard to electrons not free, to emissions and absorption of energy, or perhaps to emission alone, which must then be considered as discontinuous.

Brillouin[3] thinks that there is a loophole of escape: Planck's theory rests upon an arbitrary hypothesis with regard to strictly monochromatic resonators having very little physical basis. In giving these up, the complication of the reasoning rapidly increases, but Brillouin thinks that we can probably come out with Planck's formula without recourse to quanta. The result would, however, be inconsistent with the general theory of Lorentz previously mentioned. Possibly we may hope to reach more precise knowledge of the mechanism of absorption about which we know practically nothing, and thence get a loophole for escape. This doubtless will happen in the future.

There is another domain than that of radiation, wherein the electronic and quanta theories are clearly inconsistent, that of the properties of the metals. According to the electronic theory, the thermal and electrical conductivities of the metals, as well as many other of

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[1] See the recent article by J. Perrin in the Revue for Nov. 15, 1912.

[2] These consequences have been resumed in a notable course of lectures given this year at the Collège de France by Langevin.

[3] Brillouin, Comptes Rendus, vol. 156, pp. 124, 301, 1913.

their properties, are due to the motion of free electrons. We may, indeed, derive thus the law of Wiedemann and Franz. Electrons should therefore play an important part in the specific heats of the metals. But, according to the theory of quanta, the specific heat is uniquely related to the uncharged atomic resonators (Einstein). This accounts for the behavior of the specific heats at low temperatures. But the quanta theory has nothing to offer as to the thermal and electrical conductivities. The discordance is, however, decisive. It is perhaps premature to try to reconcile matters until measures of the thermal conductivities at low temperatures have been made, comparable with the excellent ones on the electrical conductivities made by Kamerlingh Onnes [1] at the temperature of liquid air and hydrogen.

IV. THE MAGNETON.

The electron seems to have definitely become one of our physical properties. P. Weiss [2] has for several years, and with increasing success, tried to introduce an element of magnetism, the magneton, bringing to bear upon it an imposing mass of experimental results.

He started from the theory of dia- and para-magnetism built by Langevin. [3] In that theory diamagnetism is explained by the deformation of the intra-atomic electronic trajectories under the influence of an exterior electric field paramagnetism results from the existence of a molecular magnetic moment of certain substances. Weiss has elaborated this theory so as to include ferromagnetism by means of a supplementary hypothesis, that of molecular magnetic fields proportional to the magnetizing force. This idea of an electric field is not new. Through it Ritz [4] developed his beautiful theory of the structure of the series of certain spectrum lines and the Zeeman effect. It led Weiss to formulæ which are well substantiated by experiment not only in the legitimate field of electromagnetism (the variation of the Curie constant with the temperature), but also as to the specific heats of ferromagnetic bodies. It was while looking for such precise experimental confirmation that Weiss was led to the theory of the magneton.

The measure of the absolute value of the atomic magnetic moments of iron and nickel at the temperature of liquid hydrogen, made in collaboration with Kamerlingh Onnes, led at the start to numbers 12,360 and 3,370, which divided, respectively, by 11 and 3 lead practically to the same quotient. 1.123.5. For cobalt the corresponding number was later found to be very close to $9 \times 1,123.5$. For the

[1] With regard to all these questions which we can not stop to more than sketch, see the lecture which we delivered before the Société de physique in December, 1911, upon the electron theory of metals and also the book which we have several times cited on the Theory of Radiation.

[2] Weiss, Journal de physique, pp. 900, 905, 1911.

[3] Langevin, Annales de chimie et de physique. vol 5, p. 70, 1905.

[4] Ritz, Annalen der Physik, vol. 25, p. 660, 1908.

molecule of magnetite the results were more complex and must be divided by 3 to compare them with the atom of iron. These also led to whole multiples of the same number, the factor of proportionality changing abruptly at certain temperatures as if the atom of iron underwent corresponding alterations. The number 1,235, of which all the atomic magnetic moments are multiples, will be called the magneton-gram, and its quotient by the Avogadro number (the number of atoms per gram-atom) is the magneton, 16.4×10^{-22}. The properties of a ferromagnetic body are then well explained by supposing that the magnetic moments of their atoms are simple multiples of a magneton. Magnetism will then have a granular structure like electricity.

Interesting confirmations have been made of this theory through measures of various experimenters upon paramagnetic salts or, indeed, upon other bodies. The numbers of Pascal[1] and those of Mlle. Feytis[2] are in qualitative and quantitative accord with the hypothesis of the magneton. As these numbers were calculated with reference to water as a standard, an exact knowledge of the diamagnetic constant of water became necessary. Its measure is difficult and has led to discrepant results. It has been remeasured separately by Séve[3] and by P. Weiss and Piccard,[4] who have reached concordant results close to 0.72×10^{-6} at 20° C. The theory of the magneton thus has had the merit of fixing definitely this important constant.

We are obliged to admit, however, that for ferromagnetic bodies the atom does not possess a unique magnetic moment, but has a certain number of different values according to the temperature and the chemical compound into which it enters. All these values, however. have integral ratios. The actual existence of the magneton has been demonstrated in the atoms of iron, nickel, cobalt. manganese, vanadium, calcium. mercury, and uranium. We therefore seem to have here a real. very general constituent element of matter. We may therefore think of adding the magneton to the other known fundamental elementary bodies. The attempt made by Langevin[5] to deduce the magneton from the quantum of Planck will doubtless serve as a stimulus in this direction.

V. THE PRODUCTION AND NATURE OF GASEOUS IONS.

We will not discuss here the simple. ordinary ions, such as originate from the X rays. radium, the Hertz effect. etc. For several years the accepted theory (Langevin, J. J. Thomson. Townsend. and others) was this: the negative electron. torn from a molecule by the

[1] Pascal, Ann. Ch. Phys., vol. 16, p. 531, 1909; vol. 19, p. 5, 1910.
[2] Mlle. Feytis, Comptes Rendus, vol. 152, p. 708, 1911
[3] Séve, Ann. Ch. Phys., vol. 27, p. 189, 1912.
[4] Weiss and Piccard. Comptes Rendus, vol. 155, p. 1234, 1912.
[5] Langevin, Rapport á la Conférence de Bruxelles, 1911.

ionizing force, surrounds itself with a cortege of neutral molecules; the residual positive atomic ion does likewise. Thus originate the ordinary positive and negative ions. They are characterized by their mobility K, coefficient of recombination α, and diffusion D. At very low pressures and at high temperatures these assemblages are dissociated little by little to the primitive charged center., We will see that some modification of these ideas will be necessary.

(1) Along the line of theory since the fundamental work of Langevin (Annales Ch. Phys., 1905) several new attempts have been made to explain the order of magnitude of the mobilities and their variations. Among these we should specially mention those of Sutherland,[1] of Wellisch,[2] and of Reinganum.[3] Sutherland, especially, departing from the hypothesis of molecular agglomeration, supposes that an ion is identical with the electron or the primitive atom-ion; its velocity is modified and retarded by the electric action exercised upon the neighboring ions or the molecules polarized by its approach. An apparent viscosity is thus created which explains very well the results of Phillips (see further on) upon the variation of the mobility with the temperature. The actual theory is not unlike that which led Sutherland to his well-known formula for the variation with the temperature of the viscosity of a gas.

It will be perhaps convenient to use the conventions of the older theory, considering the ions as assemblages in perpetual process of formation and disintegration in a kind of dynamical equilibrium; the charged center will then be in turn free and loaded with neutral molecules. We will see that a greater part of the experimental data makes such a convention almost necessary.

(2) With a view to furnishing useful material for the theoretical developments, many measures have been made upon the mobility, the rate of recombination, and the diffusion at various temperatures and pressures. We will mention the measures of Phillips[4] (variation of k and α with the temperature). Kovorik,[5] Tood.[6] Dempster[7] (variation at K at high and low pressures), Sales[8] (variation of D with the pressure). These measures show that ionic agglomerations disintegrate faster at low pressures and high temperatures in the case of negative ions and tend for both positive and negative ions to revert to the primitive state. This is in accord with the measures

[1] Sutherland, Phil. Mag., vol. 18, p. 341, 1909.
[2] Wellisch, Phil. Trans., vol. 209, p. 249, 1909.
[3] Reinganum, Phys. Zeitschr., vol. 12, pp. 575 and 666, 1911.
[4] Phillips, Proc. Roy. Soc., 1906, and vol. 83. p. 246, 1910.
[5] Kovorik, Phys. Rev., vol. 30, p. 415, 1910; Proc., vol. 86, p. 154, 1912.
[6] Tood, Radium, p. 113, 1911; p. 465, 1911.
[7] Dempster, Phys. Rev., vol. 34, p. 53, 1912.
[8] Sales, Radium, p. 59, 1911.

made upon flames by Moreau,[1] Lusby,[2] H. A. Wilson, and others.[3] The negative ions in flames appear to differ little from corpuscles and are scarcely loaded in their accidental encounters with molecules. The positive ion has a size of the order of magnitude of a free atom-ion and often appears to be formed of an hydrogen atom, more rarely of a metallic atom in certain flames colored by salts.

(3) It is mostly with ionization at ordinary temperatures that the newer results have been obtained. The study of ionized gaseous mixtures was first undertaken by Blanc[4] and by Wellisch.[5] According to them an ion produced in a gas A and then transported into another gas B, assumes a mobility characteristic of the gas B. This agrees with the idea of temporary agglomerations constantly destroyed and built up again. Blanc carried out his experiment with ions formed in carbonic acid gas and then transported into air. Wellisch created his ions in CH_3I of CCl_4 and then transported them into hydrogen. According to him the ionization in hydrogen is enormously increased by traces of CH_3I whereas the mobility changes only slightly. It looks as if the heavily ionized molecules of CH_3I transfer their charges to the hydrogen molecules. This is a remarkable property belonging to certain ions. The same experimenters, as well as Lathey,[6] Tyndall,[7] and others, have studied with precision the influence of traces of a foreign gas upon the mobility of ions. According to Blanc a small amount of aqueous vapor diminishes the mobility of the negative ion and increases that of the positive ion in air and in carbonic acid gas (450 and 490 C. G. S. for air instead of 380 and 600). The same occurs with alcohol vapor. The molecules of water and alcohol without doubt remain longer associated with the charged nucleus than those of air, carbonic acid gas. or hydrogen. Just the opposite is the case with the molecules of CH_3I, CCl_4, etc. From this we see also that in certain gases the positive ions finally surpass the negative ions in mobility. This. for instance, happen with chlorine.

The most remarkable fact in this connection was noted by Franck.[8] Working upon argon he found normal mobilities (of the order of 1 cm. in a 1 volt–cm. field) for the positive ions, while the negative ions had mobilities of more than 200 cm. and behaved as corpuscles free from corteges of molecules during the major part of their courses in the gas. This enormous mobility diminishes very rapidly

[1] Moreau. Comptes Rendus, vol. 148, p. 342, 1909 ; Radium, p. 70, 1910.
[2] Lusby, Proc. Cambr., vol. 16, p. 26, 1911; Phil. Mag., vol. 22, p 775, 1911.
[3] H. A. Wilson. Phil. Mag., vol. 21, p. 711, 1911.
[4] Blanc, Journal de physique. vol 7, p. 838, 1908.
[5] Wellisch, Radium, p. 241, 1909, and 1. c.
[6] Lathey, Proc. Roy. Soc., vol. 84, p. 173, 1910.
[7] Tyndall, Nature, vol. 84, p. 530, 1910.
[8] Franck, Verh. Deutsch. Phys. Gesellsch., vol. 12, p. 291, 1910.

under the least trace of oxygen; it is brought down to 1.7 cm. by 1.5 per cent of oxygen. The tendency to associate with the oxygen molecules is therefore much greater than with the argon atom. Nitrogen shows a behavior analogous to argon.

(4) The study of the charge carried by the ions has led also to important results. The method used for measuring the charge e is based upon the condensation of water-vapor upon the ions (Townsend and J. J. Thomson) and has been further perfected by Millikan [1] and his pupils. By means of a microscope a single drop of oil or other material charged by the ionized gas is observed between the horizontal plates of a condenser. Its rates of rise or fall due to the combined electrical and gravitational fields are followed, and from these rates the charge e may be computed. Thus by observing the sudden changes in the rates the new charges can be noted as they are added or taken away from the drop. It is found that these modifications of the charge of the drop always occur in whole multiples of the same elementary charge, e. The mean of the numbers found for e was 4.89×10^{-10} electrostatic units. This number accords with that deduced by Rutherford from his measures with the rays although J. Perrin found somewhat smaller values from his study of emulsions and of the Brownian movement.

An important fact was noted by Townsend [2] and his students: Ions of double charge, $2e$, or multiples of this, were found in ionized gases. This was noted in the experiments made in 1899, by means of which Townsend, measuring the diffusion coefficient D by a method using a gaseous current and comparing it with the mobility k was able to determine the product Ne of the charge of the ion by the Avogadro's number (the number of atoms per atom-gram). This was a static method and permitted the evaluation directly of the quotient k/D which equals the product Ne. This result was dependent upon the method of ionization used. At mean pressures and with the α rays from radium in air or the secondary rays due to X rays produced upon polished brass in hydrogen or oxygen, slightly moist, ions of opposite sign were both found to give nearly the value 1.24×10^{10}. However, if the secondary rays are produced in air at a sheet of brass, oxidized or covered with vaseline, or in other gases (hydrogen, oxygen, carbonic acid) upon the same strip polished and covered vaseline, the value of Ne is much greater for the positive ions. It may be found as high as 2.4×10^{10}. We conclude therefore first, that certain positive ions carry a charge $2e$; secondly, that such ions are produced by the more penetrating secondary rays which are not

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[1] Millikan, Radium, p. 345, 1910; Phys. Rev., vol. 32, p. 349, 1911.
[2] Townsend, Proc. Roy. Soc., vol. 80, p. 207, 1908; vol. 81, p. 464, 1909; vol. 85, p. 25, 1911; Haselfoot, Proc. Roy. Soc., vol. 82, p. 18, 1909.

absorbed by the vaseline. The existence of these polyvalent ions has been confirmed by Franck and Westphal,[1] who returned to the older method, using a gaseous current and devised by Townsend, in which K and D are separately measured. With X rays the proportion of polyvalent ions is about 1/10; with the α rays of polonium or the β rays of radium there seem to be no polyvalent ions. Millikan and Fletscher[2] do not agree with these conclusions, basing their objections upon the method of drops earlier described. But the earlier physicists maintain their interpretation, which also seems to be in good accord with the results from other methods (multiple charges of the α rays from radium, of the canal rays, the positive rays of vacuum tubes, according to J. J. Thomson, Gehrke, and Reichenheim and others).

However, the question must seem at present unsolved. Very recently, Langevin and Salles,[3] measuring the ratio K/D by a new direct method, have concluded against the existence of polyvalent ions in the ionization by X rays. We must therefore still leave the question open.

(5) Finally, we must note the remarkable experiment by which C. T. K. Wilson[4] has enlightened us as to the mechanism of ionization. Continuing his celebrated experiments on the condensation of water vapor on ions, he succeeded in *seeing and photographing the trail of ions*, produced in a gas by an angle α or β particle from radium or a very narrow pencil of X rays.

His admirable photographs themselves alone can give an idea of all of which we can learn from them. Upon them we see the α and β particles following their rectilinear trajectories; we learn that the X rays do not ionize directly but by the secondary rays which they tear from the molecules encountered in the gas, etc. We find also a direct verification of the hypothesis advanced by Langevin and put to experimental test by Moulin[5] in order to explain the "initial recombination" discovered by Bragg. According to the latter, the saturation current of a gas ionized by α rays is much more difficult to obtain than when X rays are used. This is due, not to an "initial recombination" between the positive atom ions and electrons just liberated, but to a localization of the ions along the path of the α particles; a saturation current is indeed much easier to obtain when the field is perpendicular to the radiation than when parallel.

[1] Franck and Westphal, Verh. der Deutsch. Phys. Ges., vol. 11, pp. 146 and 276, 1909.
[2] Millikan and Fletscher, Phys. Rev., vol. 32, p. 239, 1911, and Phil. Mag., vol. 21, p. 753, 1911. See also Townsend, Phil. Mag., vol. 22, p. 204, 1911; Franck and Westphal, Phil. Mag., vol. 22, p. 547, 1911.
[3] Langevin and Salles, Société de chimie physique, February, 1913.
[4] Wilson, Proc. Roy. Soc., vol. 85, p. 285, 1911; Radium, January, 1913.
[5] Moulin, Radium, p. 350, 1910.

VI. PHOTOELECTRIC EFFECT. (HERTZ AND LENARD EFFECTS.)

Light, and especially ultra-violet light, discharges negatively electrified bodies with the production of rays of the same nature as cathode rays.   Under certain circumstances it can directly ionize gases.   The first of these phenomena was discovered by Hertz and Hallwachs in 1887.   The second was announced first by Lenard in 1900.   Perhaps on no subject is the literature of the day greater and more contradictory, so we will note only a few of the recent results upon which the bulk of the work has been done.

(1) With regard to the Hertz effect, the researches from the start showed a great complexity of the phenomenon of photoelectric fatigue—that is, the progressive diminution of the effect observed upon fresh metallic surfaces.   According to an important research by Hallwachs,[1] ozone plays an important part in the phenomenon.   However, other elements enter such as oxidation, the humidity, the mode of polish of the surface, etc.   We are not even sure that the fatigue is absent in a vacuum.   Eugene Bloch [2] insists that we should work with an exciting radiation of definite wave-length since the fatigue varies from one wave-length to another.   He also showed that in certain instances there is an acceleration of the effect which has been refound by various workers.

A great many experiments have been made in a vacuum.   Some were undertaken to study the Hertz effect at the rear surface of a strip traversed by the light, an effect perhaps greater there than at the front surface (Stohlmann, Kleemann, and others).   Other experimenters have shown a selective effect in the case of certain metals; for instance, with the alkaline metals, according to Pohl and Pringscheim,[3] there are maxima of exciting power at wave length 0.300 μ for sodium, at 0.436 μ for potassium, and at 0.390 μ for a liquid alloy of potassium and sodium.   The general exciting power increased regularly toward the smaller wave lengths.   Several workers have also endeavored to extend the photo-electric sensitiveness of photoelectric cells into the infra-red (Elster and Geitel) or to utilize them for photophony (Bloch).

However, the greatest effort has been spent in order to find out in vacuum the variation of the initial velocities of the photo-electric electrons with the wave length.   This problem has a great theoretical interest, and the simple laws stated by Lenard since 1900 for the ensemble of radiation emitted should be studied separately for each wave length of the exciting radiation.   According to Lenard, the total number of electrons emitted is proportional to the intensity of

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[1] Hallwachs, Annalen der Physik, vol. 23, p. 459, 1907.

[2] Bloch, Radium, vol. 23, p. 125, 1910.

[3] Pohl and Pringscheim, Verh. der Deutsch. Phys. Ges., vol. 12, pp. 215, 349, 1910.

the incident light, but their velocity is independent of it, as well as of the wave length for any given metal. This odd result does not at all agree with the quanta hypothesis which, according to Einstein, leads to a linear variation of the initial energy $mv^2/2$ with the frequency. We may further in our measures replace the initial velocity by the maximum positive potential V which the metal can take under the influence of the rays (that is, the potential of the stoppage of the electrons). The first measures made upon this matter by Ladenburg[1] showed an increase of the initial velocity with the exciting frequency. Taken up by Ladenburg and Marlav,[2] Hull,[3] Hughes,[4] Richardson,[5] and others, the experiments have confirmed, although not without dispute and difficulty, the qualitative result of Ladenburg and apparently the theoretical law of variation due to Einstein. Certain writers contest this last deduction and claim a parabolic in place of a linear law of variation.[6] Our own unpublished experiments completed upon this question lead us to reserve our decision, because of the smallness of the ranges of wave lengths studied by all these experimenters. It will be necessary to take up with quartz apparatus this question, working with the alkaline metals from the visible spectrum way up to the extreme ultra-violet. This is the only procedure which will allow a real experimental test of the theory of quanta. We will close with the results obtained by Millikan[7] and his pupils, who have found in certain cases abnormally high initial velocities. It looks as if there might be some experimental error due to the mode of production of the discharge by the ultra-violet light and the influence of the electric waves from the source upon the measuring apparatus.

(2) The discovery of the ionization of gases by ultra-violet light was made by Lenard in 1900. As the effect was produced across several centimeters of air and made very great positive and small negative ions, it was natural to interpret the phenomenon, as did J. J. Thomson, as an Hertz effect upon the solid or liquid particles present in the gas. The researches of Langevin and those of Eugene Bloch[8] have shown, indeed, that the greater part of the Lenard effect is certainly due to this cause.

The Lenard effect upon the gas itself nevertheless does exist. Refound by J. J. Thomson[9] and then more decisively by Palmer,[10] it

[1] Ladenburg, Phys. Zeitschr., vol. 8, p. 590, 1907.
[2] Ladenburg and Markav, Phys. Zeitschr., vol. 9, p. 821, 1908.
[3] Hull, Phys. Zeitschr., vol. 10, p. 537.
[4] Hughes, Phil. Mag., vol. 21, p. 393, 1911 : Proc. Cambr.. vol. 16, p. 167, 1911.
[5] Richardson, Phil. Mag., vol. 24, pp. 570, 575, 1912.
[6] Kuntz, Cornelius, Phys. Review, 1910 and 1913.
[7] Millikan and Wright. Phys. Review, January and February, 1911.
[8] Bloch, Radium, p. 240, 1908.
[9] Thomson, Proc. Cambr., voi. 14, p. 417, 1907.
[10] Palmer, Nature, vol. 77, p. 582, 1908 ; Phys. Rev., p. 1, 1911.

has already been considerably studied and shows very different characteristics than those at first attributed to it by Lenard. It seems to be produced exclusively by the Schumann or extreme ultra-violet rays of wave length less than 0.180 μ. These rays will not pass through air although they will through fluorite and partly through quartz. It produces small ions of both signs, neutral centers, large ions, and ozone. It is extremely sensitive to minute traces of impurities in the gas, traces which can not be detected by other means. It can be distinguished from the Hertz effect and become very much greater. All these conclusions are drawn from the researches of Hughes,[1] Cannegieter.[2] Lenard and Ramsauer,[3] and Leon and Eugene Bloch.[4] The latter have shown also that the radiation transmitted by quartz and coming from a mercury arc ionizes the air feebly in the neighborhood of the arc and seems consequently to emit a small amount of Schumann rays. In place of the usual source of Schumann rays, a hydrogen tube furnished with quartz windows, Lenard and Ramsauer used a very powerful spark between electrodes of aluminum. Then the ionization takes place even through air and quartz and the experimenters attribute it to rays of wave length less than 0.1 $\mu\mu$, the smallest ultra-violet rays known and which were discovered by Lymann. As no measure of these wave lengths were made, it seems as probable that the effect is due to ordinary Schumann rays which have been partially transmitted by media generally opaque to them because of the great original intensity of the light. This question remains to be studied as well as the Lenard effect in general the knowledge of which is yet very limited despite the great number of interesting problems connected with it.

[1] Hughes, Proc. Cambr., vol. 15, p. 483, 1910.
[2] Cannegieter, Proc. Amst., p. 1114, 1911.
[3] Lenard and Ramsauer, Sitzungsber. Heidelberg. 1910–1911.
[4] Leon and Eugene Bloch, Comptes Rendus, vol. 155, pp. 903, 1076, 1912.

WIRELESS TRANSMISSION OF ENERGY.[1]

By Elihu Thomson.

It will be my purpose in the present discourse to outline the general nature of wireless transmission and to indicate its relationship to transmission by wire. It will also be my object to show why the wireless energy sent out follows the curvature of the earth and to explain other features which to many have been more or less puzzling. In short, I desire to present in simple terms a view of the nature of such wireless work, so that anyone reasonably informed about electrical actions can obtain, as it were, a mental picture of the process. I may here state the fact that perhaps one of the earliest experiments bearing on wireless transmission was made in company with Prof. E. J. Houston, while we were both teachers in the Central High School in Philadelphia. This old experiment to which I refer was made about the latter part of 1875, and briefly described in the Franklin Institute Journal early in 1876. It consisted in using an induction coil which would give a spark length of several inches, then known as a Ruhmkorff coil, the coil resting on the lecture table, one terminal of the fine wire or secondary of which was connected to a water-pipe ground, while the other was connected by a wire 4 or 5 feet long to a large tin vessel supported on a tall glass jar, insulating the tin vessel from the lecture table. The coil had an automatic interrupter for the primary circuit, and when in operation the terminals of the secondary were approached so that a torrent of white sparks bridged the interval between them, the gap being about 2 inches or so in length. Figure 1 shows this arrangement. When the coil was worked in this way, it was found that a finely sharpened lead pencil approached to incipient contact with any metallic object—such as door knobs within the room and outside thereof—would cause a tiny spark to appear at the incipient contact between the pencil point and the metal. This, of course, was not a very delicate detector, but was improved, as in figure 2, by putting two sharpened points in a dark box, a device due to

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Edison.   One or both points were adjusted so as to make incipient contact, and the tiny spark observed between the points was an indication of a shock, commotion or wave, electrical in its character, in the ether surrounding the tin vessel mounted on the glass jar. The tests for detecting the impulses were carried on not only in rooms on the same floor, but on the floor above and on the floor above that, and finally at the top of the building, some 90 feet away, in the astronomical observatory.   Metallic pieces, even unconnected to the ground, would yield tiny sparks, not only in the basement of the building, but in the highest part, with several floors and walls intervening.   I mention this old experiment particularly because it has in it the elements, of course in a very crude form, of wireless transmission, the wire and tin vessel attached to one terminal of the coil being a crude antenna with its spark-gap connection to ground, as afterwards used in wireless work by Marconi, and it also shows a rudimentary receiver or detector, a metallic body arranged in connection with a tiny spark gap, so that electrical oscillations in such body would declare themselves by a faint spark at the gap.   It was understood by us at the time that after each discharge of the coil there was, as it were, a shock, or wave in the ether consisting of a quick reversed electrical condition, and it was even imagined that there might be in this process the germ of a system of signaling through space.   This old work was almost forgotten when it was recalled by the later work of Hertz, about 1887, who demonstrated by suitable electrical apparatus that waves of the general nature of light or heat could be generated, which waves are transmitted with the velocity of light, 186,000 miles per second, and that by suitable resonators or detectors these waves could be made to declare themselves by tiny sparks.   The Hertzian oscillator was, as it were, an electrical tuning fork, having an actual rate of vibration peculiar to itself and dependent on its form and dimensions.   It was fed with energy from an induction coil and across its spark gap an oscillating discharge took place, which, at each impulse, died out like the discharge of a condenser, but during this discharge it electrically

stressed the ether in one and the other sense, so that an electrical wave was radiated in certain directions from the oscillator. It was found that these waves could be refracted, reflected, and polarized, and, in general, dealt with as extremely coarse light or heat waves. We shall refer to these, however, farther on. The general result, however, of the Hertzian experiments was to connect electrical waves in the ether surrounding the apparatus with the light and heat waves and prove the identity of the two kinds of radiation, the differences being only those of wave length or pitch.

Since the Hertzian waves were sent out from the Hertzian oscillator in substantially straight lines, and since in the early days of wireless telegraphy it was common to regard wireless waves as of the same nature or as almost identical with Hertzian waves, the fact that the wireless waves were found to follow the curvature of the earth became a difficulty to be explained. Speaking for myself, I have never found the difficulty to exist. There is really no reason why the waves should not follow the curvature of the earth, as it will be one of my purposes to show. We will, however, approach the conditions of wireless somewhat gradually.

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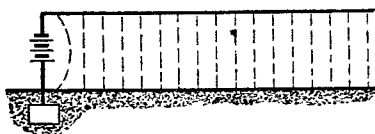
Fig. 4.
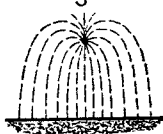
Fig. 5.
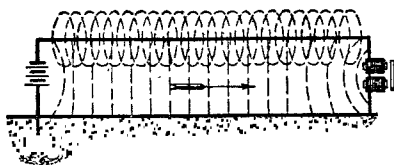
Fig. 6.

We will first consider an ordinary wire transmission of the simplest type. Let us assume a line of wire, as in figure 3, insulated and connected to one terminal of the battery while the other terminal is earthed or grounded. A simple telegraph system on open circuit would represent this arrangement. The only effect is that the battery supplies a small charge to the line, producing a potential difference between the insulated line and the earth, assuming, of course, that there is no leakage of any kind to disturb the conditions. As soon as the charge is established in the line at the full potential of the battery, which, in ordinary cases, would take place within a very small fraction of a second, a steady or static condition is reached, which might be indicated by electrostatic stress lines drawn from the wire to the ground, as illustrated in figure 3 by the fine dotted lines connecting the horizontal line to the ground surface below. If the wire be viewed on end (fig. 4), we must represent these stress lines

as extending out radially from the wire and bending over to meet a considerable portion of the ground surface below. As this arrangement is constituted, there is no energy transfer and the condition is static only. If now the far end of the line is earthed, as through an instrument or device which uses energy, as in figure 5, at the moment of such connection there would be a lowering of the intensity of the stress toward the receiving instrument and the line would be discharged were it not for the maintaining action of the battery, which still keeps up the difference of potential between line and ground. If the line is without resistance, this potential will have the same value all along the line, especially if the line is of uniform section and of uniform distance from the ground. The moment, however, the instrument at " I " takes energy from the line a current is found in the wire and a return in earth, and there is, so to speak, a flow of energy in the space between the wire and earth and in the ether surrounding the wire, in the direction of the arrow—that is, from the generating end to the receiving end. Surrounding the wire at this time there will be a magnetic field, which may be represented by whorls or lines of magnetism, so called, wrapped around the wire like so many hoops of all sizes (fig. 6), expanding in size away from the wire in all directions; and a similar magnetic effect, of course, is also produced by the return current in the earth. But on account of the conditions of conduction in earth being very devious and irregular, it would be difficult to map the magnetism generated. The system of magnetic whorls so developed on the flow of the current in the system reaches, for any definite current, a definite density after a short interval. In other words, the density of the magnetic field between the wire and the earth increases only up to a certain point. If the current, however, be doubled in any way, that field is doubled in density or there are twice as many lines packed in the space around the wire. If now we took instead of an earth-connected circuit one in which there are two wires extending from the generating battery or generator, the conditions will be the same except that the stress lines will now radiate from each wire and connect the wires by lines directly between them and by other curved lines outside. Such lines, or otherwise conceived " tubes of force," represent the static field or
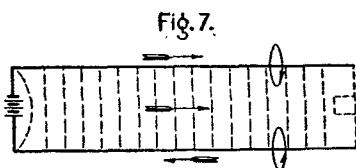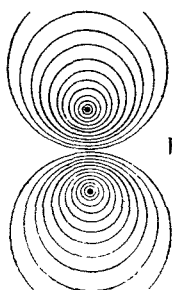
Fig. 7.

Fig. 8.

Fig. 9.

the density and directions of electrostatic stresses in the electrostatic field where one wire will be positive while the other is negative. If, as before, the ends of the wire are free or open-circuited, no energy is transmitted, and the mere static stress exists. If, however, the wires are connected through an instrument receiving energy or utilizing the energy, then the magnetic system is developed, surrounding each wire and passing between the wires, and on the establishment of any given current these lines accumulate at a rapid rate until, in a small fraction of a second usually, a limit is reached. The magnetic field may then be said to be fully developed. Outside of the pair of wires the magnetic disturbance extends to very great distances, but is necessarily weak far away. The magnetic whorls in this case do not center themselves in circular paths around the wires and at equal distances therefrom, but between the wires they are more condensed or pushed toward the wires themselves—crowded, so to speak—while outside of the wires they expand (figs. 8 and 9). It must be remembered that these lines of force are merely symbols for what may be likened to a magnetic atmosphere. They indicate the density and direction of certain actions in the ether, called magnetic. It will be important to note, both in wire and wireless transmission, that the energy is transferred in the surrounding medium. The wire in ordinary wire transmission is, in fact, a sort of guiding center or core around which this ether disturbance carrying the energy exists. The wire may be bent or coiled, expanded or contracted without altering the essential nature of the process. So far, then, ordinary wire transmission is really a case of wireless transmission, with the wire for a guiding core for the energy (fig. 10).
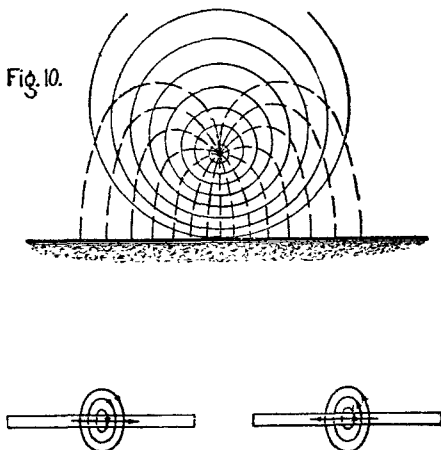
It would take us too far to attempt to explain or theorize on the modern view of the passage of electrons in the wire forming the current, and the field they carry with and about them in giving rise to the stresses in the ether surrounding them. Suffice it to say that a moving electron must not only be accompanied or surrounded by the static stress field which it produces in the ether but also by a magnetic effect representing the energy of motion possessed by it. When a current which has been started in a circuit reaches a definite value it may be said to have reached a steady state. It would then

be a continuous current of constant value. Energy can be steadily extracted from such a system only by introducing some apparatus connected with the wire which is the guiding core for this energy.

Let us now consider the case of current of a different character, a fluctuating—or better, an alternating current. Let us substitute for the battery an alternating current generator, and assume a single wire with an earth or wire return, as in figures 3 and 5. Here the wire merely becomes positive and negative alternately, for the circuit is incomplete or unconnected as a circuit, and the stress lines from wire to earth or to other wires reverse periodically their direction plus to minus and minus to plus. This is true, of course, whether the earth be replaced by a second wire or whether three or more wires be involved, as in a three-phase alternating current circuit. By connecting any two of the wires through an energy-receiving ap-
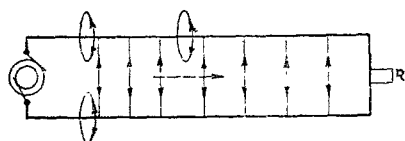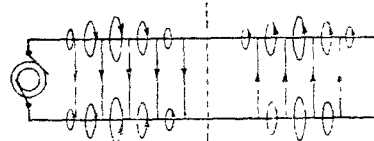
Fig. 11.

paratus R (fig. 11), the same action that takes place with the continuous current may be reproduced except that the energy now comes in waves and is not a continuous flow. In ordinary cases there are 60 complete waves or complete changes from plus to minus and back to plus in each second, and the system is then called one of 60-cycle frequency. A further important difference is to be noted between the alternating-current condition and the continuous. The action in the ether around and between the wires is now in the form of waves, both magnetic and electrostatic. Between wires there is an increase of electrostatic stress to a maximum, a diminution to zero, a reversal, etc. The magnetic field also rises, falls, reverses, and so on synchronously. The condition is no longer static, the medium around the wires is in a dynamic state and it is now possible to abstract energy steadily from it without actually diverting current from the line. We can, in fact, by such a system produce in neighboring conductors similar disturbances or currents, and along with these disturbances we may deliver energy.

Fig 12.

The alternating-current transformer is then merely a device for bringing two or more circuits together as near as possible and enhancing the magnetic values which would normally exist around such circuits by the addition of an iron atmosphere, the iron core, so that the greatest possible transfer of energy from one (the pri-

mary circuit) to the other (the secondary circuit) may be accomplished. But in the wire itself, which leads from an alternating-current source, since there is an action called a current which changes, pulsates, or alternates, we have also around the wire core waves in the ether which, in fact, spread to very great distances; some small portion of the energy of each impulse not returning to the system, but passing outward into space as radiated energy.

This radiation may be a very small amount per cycle, especially where the outgoing and return wires are near together and parallel, and with low frequencies, such as 60 cycles, on account of the low number of waves per second and the low speed or rate of change in the fields surrounding the wire, the amount of energy carried off by free radiation into space is indeed negligible. But if we raise the frequency we raise the amount of energy which can be radiated proportionately to the number of waves per second, and we also make the rate of change higher and the wave slopes steeper, so that as the frequency rises the radiation factor becomes more and more important in dissipating the energy of the system. It will be noticed, however, that such energy is not directed energy. It is diffused through space around the electric system at work and passes off to illimitable distances. Since these impulses in the wire, the electrical waves sent along the wire (with the wire as a guiding core), can at the maximum move with the speed of light—186,000 miles per second—it follows that if the line is sufficiently long or the transmission sufficiently extended or the path of radiation sufficiently distant the wave stresses or fields or currents can exist at different parts of the system in phases either much displaced or entirely opposite. This may be rendered clear by stating that while one portion of a very long line might be positive to earth another portion half a wave length distant from the first along the same line would be negative to earth (fig. 12). In other words, there may exist upon the system at the same instant a succession of waves in opposite phase. Just as in vibrating strings in musical instruments or vibrating columns of air in organ pipes there are stationary waves, nodes, and internodes, so in electrical systems in vibration there can be nodes and internodes if the conditions are selected for obtaining that effect. Here the dotted vertical line indicates the nodes of the waves. We may thus have so-called stationary electric waves (fig. 12).

We find that on raising the frequency of an alternating-current system from, say, 60 cycles, the ordinary frequency, to 600 cycles, an effect which at first was hardly detectable now becomes important. It is the so-called " skin effect " whereby the current in a wire circuit tends to concentrate itself on the outer skin of the conducting wire, neglecting the inner copper, so that the inner core of the wire

might be left out. .Consider the frequency still further raised, say, to 6,000 cycles, this "skin effect" of the conductor still further increases until the copper in the interior of a circular wire of a considerable size is now quite useless, and to get the advantage of such copper we must, as it were, take it out or spread it in a number of parallel wires spaced apart, or make the metal of the conductor in the form of a long sheet or in the shape of a thin tube or a cage of wires (fig. 13). This, in electrical terms, improves the conductivity and reduces the opposition due to self-induction; the inductance counter E M F. Let now the frequency be still further increased to tens of thousands or hundreds of thousands of cycles per second; then our conductor must necessarily become a still thinner or a still more extended sheet.

At the same time, if there are considerable differences of potential between the conductors thus arranged, the radiation factor may at last become very important, so that if the parts of the circuit are far apart, free radiation into space may dispose of a large fraction of the energy sent out. In the Hertzian oscillator, deducting that lost in the spark gap, practically the whole of the remaining energy supplied is radiated into space.

Fig. 13.
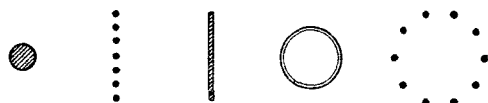
Fig. 14.

Fig. 15.
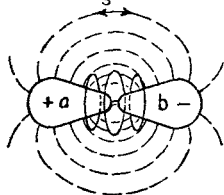
Fig. 16.
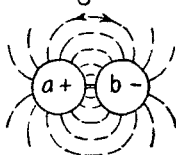
The wave frequency may be very many millions per second, and the waves produced are in the nature of coarse light and heat waves. Figure 14 exemplifies diagrammatically the fact that with very high frequency waves a conductor carrying such waves will have surrounding it, if the space is unrestricted, magnetic systems of lines reversed in direction with nodes between. the distance apart of these waves or nodes being determined by the frequency in relation to the velocity of light, each complete wave outside the wire occupying a length equal to the velocity of light. 186,000 miles per second, divided by the wave length or frequency.

Figures 15 and 16 represent forms of Hertzian oscillator, consisting of plates or spheres a b of metal, separated by a small spark gap and charged in any suitable way, plus and minus with respect to each other. and allowed to discharge across the gap. The charges are then interchanged between a and b at a very high rate,

though the waves decay rapidly, and the system vibrates only for a short time or until the energy of the charge is dissipated in ether waves of exceeding high pitch into the surrounding medium. Were there no energy lost in the gap itself for forming the spark, and if the metal were a perfect conductor, the full amount of energy represented by any initial charge would be dissipated in the ether in these ether waves. Marconi, however, in his development of wireless telegraphy did not use the complete Hertzian oscillator. In setting up his transmitting antenna he took substantially half an oscillator, the other half being, so to speak, a phantom—the reflected image of the first half, as it were, in the surface of the earth, generally the sea surface. It would be represented by taking an extended copper sheet or surface coated with a fairly good conductor to represent the earth's surface and mounting above it, but insulated from it, a metal body, such as a vertical rod, which could

be charged and which could discharge to the sheet through a small air gap. In this arrangement not only would waves be sent out into the surrounding ether space, but there would be current traversing the sheet as waves of current around the spot where the discharge of the insulated body took place. In fact, I think it would be pos-

Fig. 17.

Fig. 21A.

sible to represent experimentally a modern wireless system with a diminutive antenna to represent the transmitting station, and extended copper sheet to represent the earth's surface, and with investigating or receiving antennæ set up here and there or moved from point to point on the extended surface.

Here, although the disturbance and the energy conveyance is in the ether around the antenna (or the part representing the half of the Hertzian oscillator), the energy is guided in its direction by the current in the sheet representing the surface of the sea, just as in the wire transmission the energy is guided by the wire as a core. On account of the enormous extent of the earth's sea surface, there is no need of a return circuit. The energy sent out moves in all directions, guided by the conducting water surface or land surface, as the case may be. There will necessarily be a rapid attenuation
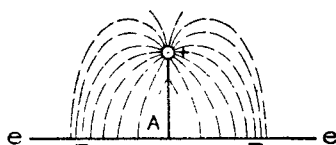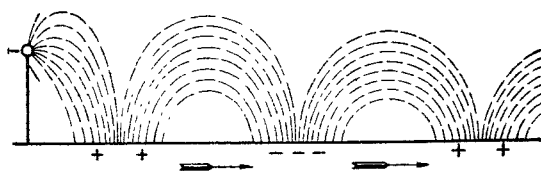
of the energy as it leaves the sending or transmitting antenna and spreads out to fill a wider and wider space around it. The higher the sending antenna the greater the distance which can be reached before the attenuation is too great for imparting signals.

Let us consider for a moment by the aid of a figure the actions which must occur in wireless transmission on the sending out of energy from the transmitting antenna. Referring to figure 17, we will represent by e—e the surface of the earth as if it were flat, and for moderate distances this will be substantially the case. We will erect on that surface a tall mast A of conducting wire or wires which, at the top, shall have an extension to increase its capacity. This might be a large ball of sheet metal. Usually, for construction to be practicable, it is a set of wires—a sort of cage or a skeleton body. Now, by any system, inductively, conductively, or otherwise, or by what is known as close or loose inductive coupling or what not (figs. 18,

Fig. 18.   Fig. 19.   Fig. 20.
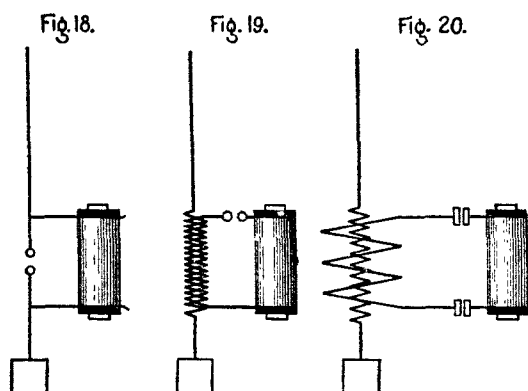
19, 20) we cause electric disturbances, such that at one instant the top of the antenna becomes positive and at the next instant negative, many thousands—even hundreds of thousands—of t i m e s per second. In other words, we impress a high-frequency wave upon this vertical mast. We will try to present an instantaneous picture or form an instantaneous image of what the condition is at the beginning of the process.

Let us suppose that the charge is positive at the top, and necessarily the surface below and surrounding the mast will be negative. Electrostatic lines will extend from the mast, and particularly from the expansion at the top down to the earth's surface in all directions around the antenna, as in the figure. The medium around the antenna will be stressed electrostatically. This would be all, provided the charges were stationary, but the system we are considering is dynamic. The plus charge is replaced by a minus charge at the top, and a current of a high frequency runs up and down the antenna, but so also does this current extend into the sea radially from the foot of the antenna, replacing the negatively charged area by a positively charged zone, as it were, while the top of the antenna is now negative where it was formerly positive. (Fig. 21 A (p. 251), one side only shown, and fig. 21 B, in plan.)

As this action goes on, however, the zone of charged surface widens, and ether waves are, so to speak, detached from the antenna, and electrostatic lines join now through the air or ether above the successive zones which surround the antenna as great circles or flat rings of the sea surface.   A plus area is followed by a minus, a minus by a plus, etc., and to indicate the effect in the space above, we draw lines which follow these areas, extending up into the ether above the surface, but moving away from the antenna with the velocity of light. The moving charges in the sea surface represent radial currents which are in opposite phase at different portions of the sea surface, and spreading at 186,000 miles per second, and these currents necessarily generate magnetism or lines of magnetic force in the medium directly above them.   These lines extend around in zones with diminishing intensity upward from the sea surface as the distance from the surface increases.   Even within the water itself a similar action, but more restricted, takes place.   The charges in the water are connected by electrostatic stress lines, and the compensating magnetic field follows the current, but this " under water " effect does not concern us. as what we work with is the energy conveyed in the space above the sea, the other not being so easily recoverable.

Fig. 21 B.

The system as thus far constituted is merely an arrangement for delivering energy in high-frequency waves to the widespread medium around the antenna.   There is no selective action whereby it is focused anywhere—it is as a " voice crying in the wilderness."   It can be picked up or recognized in any direction by anyone who is within range.   If. now, we are to receive signals such as are made by interrupting or disturbing at intervals this system of radiation of energy, as in ordinary telegraphy. we must set up somewhere a receiving apparatus which will enable us to pick up whatever small fraction of the energy reaches it and. if possible. a sufficient fraction of such energy for the recognition of the signals.   If the signal can be recognized—no matter how small the fraction of the energy sent out is which we collect at the receiving station—the system succeeds. There is no question of efficient transmission, as there is in the ordinary power-transmission systems.   The latter are for the transmission of energy with as little loss as possible, the former for the transmission of signals only.
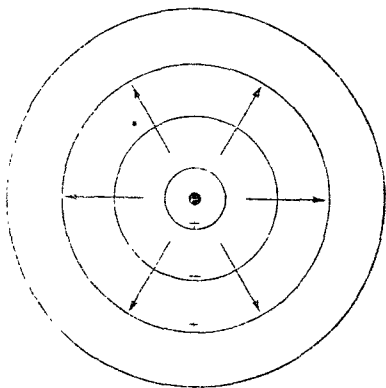
In the antenna transmission just considered it is assumed that the surface of the earth is, generally speaking, a good electric conductor. The surface of the sea is sufficiently good. Dry land surface, however, is not a good conducting sheet, and even though moist it is generally so irregularly conducting that obliteration of the waves and loss or absorption of the energy must necessarily occur. Obstacles, such as dry rock ranges, may absolutely prevent the waves from passing over them. It must be borne in mind that these waves have no inertia. as such, and that the energy must be guided to its destination by a conducting sheet. This calls to mind the efforts that were made to connect Lynn and Schenectady by a wireless system, but without success. Occasionally signals were received, but in general they were too indistinct to be recognized. It is more than probable that the dry rock ranges of the Berkshires in western Massachusetts were sufficient of an obstacle to prevent the energy of the waves getting across them.

It is also to be questioned whether there may not be another action which interferes with and disturbs the integrity of the waves. It is conceivable that waves may follow a water surface, even around a cape, and that a portion of the energy may take a short cut across the land of the cape. If this be so. the longer course would be around the cape. the shorter course across the land. The wave lengths would remain the same, and an out-of-phase relation or interference phenomenon would take place to a greater or less extent. It is manifestly necessary that the energy, by whatever course it follows, shall reach the receiving apparatus in phase.

Let us now consider for a moment the conditions at great distances over the earth's surface. At moderate distances from the transmitting antenna the surface may be considered as flat. The conducting sheet guiding the energy is flat or plane, but at great distances the curvature of the earth's surface becomes an important factor. For a time there was a great deal of discussion as to the reason why the energy in the wireless transmission seemed actually to follow the curvature of the earth, instead of going straight away. as in the case of Hertzian or heat and light waves. If the waves had been generated by a large Hertzian oscillator. it would not be possible for them to so follow the earth's curvature. but inasmuch as they are in wireless work produced and. as it were, positioned upon a conducting sheet (the sea surface), then it follows that the energy must be guided by that conducting sheet or surface, regardless of its extent or its curvature. I have never been able to understand why so much discussion has been needed to clear up this point. Wireless waves have no inertia— they follow the course of the charges which produce the stress and of the magnetic field. due to these charges in motion. These charges in motion are the currents in the conducting sheet. which may or

may not be curved. In the curved surface of the ocean the zones of charge continually expanding, plus and minus, respectively, are still connected by the electrostatic lines above them, and the moving charges still generate the same magnetic field as they traverse radially or outwardly in the curved instead of the plane sheet (fig. 22), and this curved conductor still guides the energy, just as the wire does in ordinary transmission. It would seem, if this is the correct view, that at a distance comparable with that of a quadrant of the earth's circumference the form of the wave would be such as to cause the stress lines to lean backward with respect to the surface, tending to keep their original relation to the transmitting antenna as they were detached therefrom (fig. 22, at L). This assumes that the velocity of transmission is the same as that of the speed of light, both for the currents in the sea and for the stresses above it.

Marconi's success as a wireless pioneer depended largely upon the choice of a sufficiently sensitive receiver. Two elements are necessary in the receiver. First, a conducting structure which gathers up the energy from the medium, the ether, above the earth's surface. The other element is a sufficiently delicate means for detecting the slightest changes of electrical condition, not only actuated by what little energy is received, but so modifying it that it can operate a signal which can be seen or heard. Usually the receiving antenna is a vertical conducting mast or cage, like the sending antenna. In fact, the functions of sending and receiving are interchangeably used on the same structure; the same antenna may be at one time used for transmitting and at another time for receiving.

The receiving antenna (fig. 22) serves to relieve the electrostatic stress in its vicinity, much as a lightning rod may act to relieve cloud to earth stresses. If its direction could be made to follow or be parallel to the actual course of the transmitted lines in the space near it, it would be most effective, and if, further, it could extend sidewise over a considerable extent of the wave front, it would gather up more energy. These conditions, however, can at best be only approximately met. If the receiving antenna were of such a character as to have no oscillation rate of its own (a damped circuit) it would receive energy in a small amount from the transmitting antenna independent of the frequency, but as this would in most cases be far from sufficient, it is desirable to accumulate energy in the receiver from a train of waves at a definite rate. To do this the principle of syntony or tuning is brought in. Everyone is familiar with the two tuning forks, where one is sounded and the other is placed at a distance away. If the two forks are not in harmony, no effect of the one fork on the other follows, but if they are accurately tuned in unison, the sound of one fork at a considerable distance from the other starts the second in vibration and produces an audible sound

from it. The second fork is, in fact, a structure particularly well adapted to gather up the energy of the sound waves which reach it, receiving from each wave a small portion of energy and accumulating such energy until the fork itself is brought into palpable vibration. By applying this principle in wireless telegraphy—that is, by causing the rate of vibration or frequency of the electrical waves to be the same in the transmission and in the receiving antennæ systems, constructing both to possess a normal rate as if they were to be electrical tuning forks of the same pitch—the amplitude of the received impulses is so greatly increased that signal strength is reached where otherwise failure would have resulted. The one thing which has characterized the more recent advances in wireless telegraphy has been the accuracy of tuning and the removal of disturbing influences which would interfere with the tuning.

Formerly the transmitting circuit was excited by means which tended to disturb the actual normal rate. If excited inductively, the inducing or primary circuit had a rate of its own, which was apt to interfere with that of the vibrating antenna system. However, what is known as loose coupling (fig. 20), instead of close coupling (fig. 19), to the primary or exciting circuit causes such
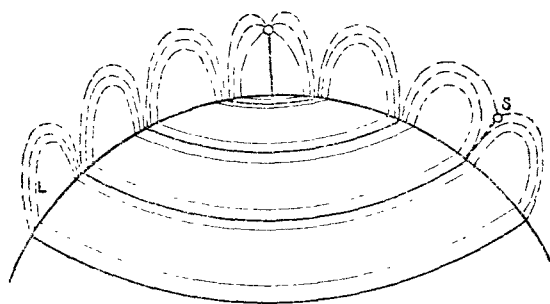
Fig. 22.

confusion of rates to be nearly negligible if, particularly in the exciting circuit, the current is well damped. as it is termed, or confined to a single brief impulse as far as possible. In such case the antenna circuit, in transmitting, acts as if it were a bell struck with a sudden quick blow. and it vibrates at its own rate without disturbance or interference. At the receiving end (and there may be, of course, many receivers in the space around the transmitting antenna), the "listening-in" process consists in adjusting the rate of vibration of the receiving circuit by variable condensers or inductances, so that the maximum loudness of the received signals is attained. The two systems, transmitting and receiving. are then in tune.

Accuracy of tuning is evidently very important if stations are to be simultaneously transmitting when near together. as only in that way can one station send out energy without interfering with the other; the particular receiver for which the signals are intended being tuned for the particular antenna sending these signals. In spite

of the accuracy of tuning, however, high-power stations may, in fact, cause high frequency waves of high potential in all surrounding wire or metal structures if near enough. Burn outs, or even fires, may occur from this cause. Hence it is desirable that high-power sending stations should be well removed from centers of population where there are electric circuits and electrical apparatus likely to be interfered with or injured.

It may be here pointed out that the limit of potential which is available in wireless transmission is the same as that of long distance transmission by wire and for the same cause. Naturally, if the potential on the sending antenna can be raised, the amount of energy which can be put into the wave impulses will be increased, but there comes a time when an increase of potential on the wires of the antenna gives rise to a corona loss—much as the increase of potential in wire transmission produces a corona loss. The conductors of the system, in such a case, are surrounded by a blue discharge which is even visible at night and which frequently can be heard. When this condition is reached every further increase of potential simply increases the corona loss without adding correspondingly to the energy transmission. Just as in wire transmission it can be avoided by increasing the diameter of the conductors, so in wireless work it could be avoided by constructing the antenna system of hollow tubes with smooth exteriors, and the imagination may be permitted to depict a sending tower of polished metal surmounted by a sphere of similar material and worked at millions of volts. No limit can be set to the amount of energy which might thus be radiated, and no limit as yet can be set to the distance around the earth to which signals might be sent by such means.

One curious fact which has been developed in the work of wireless signaling is that daylight, especially sunlight, is very detrimental to transmission as compared with the night. That is to say, if the wireless waves are to traverse the sea surface in sunshine, the chance of receiving them in sufficient force to produce signals at great distances is far less than when they are sent at night. It is probable that this difference is not due to any single cause—it may be the effect of a combination of causes. It is a notable fact, too, that this difference between the effectiveness of daylight transmission and night transmission is accentuated at the higher frequencies.

Though the cause is still somewhat obscure, we may venture a suggestion or hypothesis which may have a bearing on the case. Referring to figure 23, we have tried to show the condition. The electrostatic field at the water surface at the same instant is as in figure 21 produced in zones around the antenna *A*, spreading with approximately the speed of light. It is well known that under the

action of the violet and ultra-violet rays of light any surface, having a negative charge will leak its charge and ionize the air near it. This may occur in sunlight over such areas as are marked minus in the figures, and the several minus signs would mark or indicate air ionized and negatively electrified over the negatively charged zones. No action would be expected over the positive areas or zones. But the zones are not stationary; they are widening very rapidly, so that a positive zone or zones takes the place of negative so far as any location is concerned. This may be expressed by saying that the water surface which at one instant was negative and gave out negative ions under the influence of light would, in an exceedingly small fraction of a second and before those ions could get away from electric contact with such surface, become positive and the free ions would now return and neutralize a portion of the positive charge. Thus the negative zones or wave elements would lose part of their charge to ionize air, and the positive waves would be weakened by such negative leak neutralizing them in part. This action, however feeble at each wave, would be continuous over hundreds if not thousands of miles, and continuously damp out the widening system of waves. The effect would be less marked with low frequency
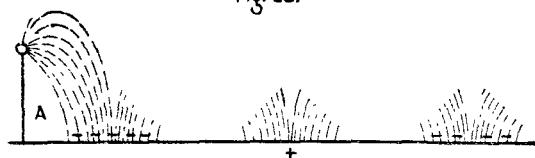
Fig. 23.

Fig. 24.

waves, as there would be a proportionately less number of opportunities for this neutralization per second. Besides, with the lower frequency there is more time for the separation of the negative ions to such distance from the water surface that they do not combine with the positive charges; being, as it were, better insulated from them or diffused in the air stratum.

In figure 24 an attempt is made to picture this action of attenuation in the presence of light. The negative charges in the air layer, as in figure 23, have no positive charges under them, the encircling lines about the + and − signs indicating combination and neutralization.

When the wireless waves reach the receiving antenna, owing to attenuation from spreading or loss as above, they are very feeble. The

daylight effect, as pointed out by Fessenden, is much less with the lower frequencies, such as 100,000 per second as compared with 600,000 or 800,000 waves. Consequently there is not the same great difference in strength of signals between night and day work with such lower frequencies. Moreover, frequencies of 100,000 or even 200,000 are capable of being generated directly by high-speed high-frequency dynamos with the added advantage that the waves sent out are maintained at their full amplitude and are not, as with waves produced by spark discharges, subject to damping or decay from maximum to zero after a few oscillations.

Whatever the nature of the waves sent out, there is in all cases the need of an exceedingly sensitive apparatus for converting the slight electric effects upon the receiving antenna into signals. The original apparatus of Marconi included the Branly coherer, used by Lodge in Hertzian wave transmission as a detector. It is indicated in figure 26 at K, with its battery and sounder magnet M. The receiving antenna discharge in passing to earth broke down the insulation of the filings of the coherer, so that the local battery current could pass in the circuit, including a magnet M and so record the signal. The liquid barretter of Fessenden, the various forms of rectifying crystal detectors and magnetic detectors. have been extensively used. Our time does not permit a detailed description. Figure 25 indicates at C a crystal detector rectifying the impulses from antenna A so as to work a high-resistance telephone receiver T, to which the operator listens. Figure 27 shows the same apparatus, but connected inductively to the antenna circuit by a transformer.

Fig. 25.   Fig. 26.   Fig. 27.
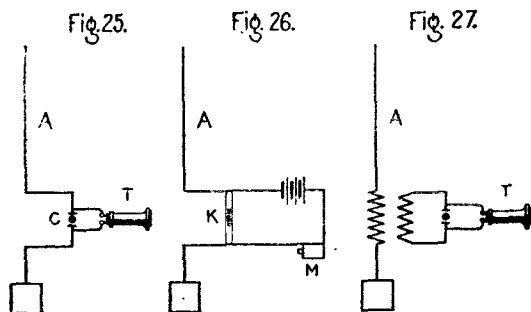
reaching the telephone T was such as to produce a low note, the signals were easily drowned by extraneous noises or induced effects. He found that the human ear reached a maximum of sensitiveness at about 900 waves of sound per second, so that the signals were heard distinctly when otherwise they would have been missed. This is the meaning of the substitution of dynamos of about 500 cycles for exciting the wireless antenna in place of the ordinary machines of lower frequency.

The problem of wireless telephony has attracted attention for a number of years past. I well remember witnessing some of the

earlier work of Fessenden in this fascinating field, in which he was pioneer. The wireless telephone speech was free from all disturbing noises and interferences so common on ordinary telephone lines. Briefly, such telephony depends on the ability to control the voice waves and vary in accordance therewith the energy given out by the transmitting antenna and to do this with a fairly large output of energy.

By employing a method I described about 1892, it is possible to generate a continuous wave train by shunting a direct current arc with a capacity (condenser) in series with an inductance, the frequency rate depending on the electrical constants of these parts of the apparatus. This system, which was the subject of the United States patent taken out by me in the early nineties, has been variously called the Duddell singing arc, or later the Poulsen arc. Poulsen employed it with modifications in his system of wireless telephony. Long before this work of Poulsen, Fessenden had used a high-frequency dynamo for securing the continuous train needed. A suitable microphone transmitter was made to so alter the relations of the waves in transmitting and receiving antennæ, that voice waves could be received in an ordinary telephone connected with the receiving antenna system.

Much progress has been made in this department of wireless work, and such telephony between Europe and America may yet become practicable. Methods are being worked out whereby it may be possible to mold outputs of many kilowatts of energy so as to have them vary with the voice waves, and when this is done many problems, the solution of which now seems remote, may become solved and the results prove of great practical value. It was not, however, my intention to devote time to these later researches, but to endeavor to present to the mind's eye a view of the nature of wireless transmission which should show the similarities to ordinary transmission by wire and also the differences. Furthermore. I hope I have shown it to be evident that future transmission of energy at high efficiencies will still demand the wire core for guiding that energy to its destination.

OIL FILMS ON WATER AND ON MERCURY.[1]

By HENRI DEVAUX,

Professor on the Faculty of Sciences, at Bordeaux.[2]

[With 7 plates.]

Certain phenomena of daily observation are of great interest to the physicist. Especially so is the expansion of oil over the surface of water or of mercury. I have studied this matter for a long while and from all my observations several unexpected facts stand out.

Films of oil tell us with the greatest nicety of the discontinuity of matter, and the dimensions of molecules. They also give us valuable information as to the field of molecular action. For our observations we will find that there is no need of complicated apparatus; basins, paper, threads of glass, a pipette, a sieve with some talc powder, and finally some oil and benzole suffice for the greater part of the experiments. As to measuring instruments, a double decimeter will do, although its divisions be a million times greater than the diameter of the molecules. Though it seems like measuring microbes with a surveyor's chain, we will see that the measures not only can be made but made with great precision, because of a very remarkable peculiarity of films of the thickness of one molecule. We will yet further see that the smallest variation in homogeneity engenders considerable differences in the surface tensions, causing the molecules to become exactly equidistant.

I. THE LIMIT OF THE EXPANSION OF OIL OVER WATER.

We will first look at an experiment of elementary simplicity yet fundamental. Let us pour some water into a photographic tray and then remove all the impurities from the surface by placing upon it just a sheet of thin paper. Then I scatter on the surface a little talc powder and place upon it a *trace* of oil by means of a very fine capillary tube. The oil spreads out rapidly from the talc in a circle, since the normal surface tension of the water is considerably lowered. But if there is very little oil, such as the capillary will take up by just touching the stopple of the bottle, the expansion stops suddenly, so that we have a circle of oil surrounded by free water.

Yet is the water really free? Perhaps there are traces of impurities which stop the extension of the oil. This is not the case.

Let us touch with a trace of oil another point distant from the first one touched; a new circle forms and extends outward from the talc, but the first one is in no way affected. No equilibrating impurity exists outside of the first circle, otherwise its surface would have been deformed and diminished. There is therefore a real limit to the extension of oil upon water. And when that limit is reached the surface tension is both that of pure water and of oiled water.

Let us throw upon this water some grains of camphor dust. At once we see the grains in lively motion, but everywhere with apparently the same speed whether within or without the oiled region.

We may proceed differently. First spread over the water a sheet of oil, powder it, and then try to enlarge a little portion of the oil film by means of a strip of paper placed across it and over the edge of this dish. At once the whole surface is covered, since the layer of oil was somewhat thick. But there always comes a time when the extension stops: the oiled region marked by the talc remains behind, although there is a surface of water free from both talc and oil. The limit is extremely clean cut and we have side by side two surfaces with the same surface tension—one of free water, the other of oiled water at its maximum extension.[1]

If at this moment a little camphor dust is scattered on the surface, the grains will be seen in active motion. In getting out of the way of the talc they act like little tadpoles. If the surface is reduced to one-half all motion stops suddenly and the talc gathers around each particle of camphor. We may put upon the water a little tin boat

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[1] In 1891, Mlle. Pockel pointed out to Lord Rayleigh in a letter published in Nature (English) on the 12th of March, p. 437, some experiments relating to these facts. In enlarging progressively a surface of oil upon water or of water soiled with any other impurity, the tension of that surface varies continuously (abnormal condition); it increases slowly at first, then very rapidly, and reaches a maximum. Any further extension from the maximum point leaves the tension invariable (normal condition). If Mlle. Pockel had scattered an inert powder upon that surface to render it visible, she would have realized that, as soon as the maximum is reached, the oil would extend no further.

such as I devised in 1888,[1] and which is shown full size in figure 1. A little fragment of camphor is stuck with wax in a notch in its rear. A little mast bearing a streamer is fixed in the middle. This little boat, placed upon the water, moves rapidly and continuously so as to be seen from all parts of a room (pl. 1).

I used this device the 19th of April, 1912, in Paris before the Société de Physique. Placed at first upon water with a film of oil at its maximum extension it traveled just as on pure water, leaving in its rear a large wake; the talc was thrown out with a marked vibration whenever it came in contact with the camphor, just as if the camphor corresponded to the propeller of the boat. I diminished the surface. At once the wake became smaller. The boat slowed up. I made the surface yet smaller. The boat stopped. I increased the surface, the boat again moved.

We may thus, by the simple movement of a capillary barrier (a strip of paper), show to a whole audience the effect of sudden and considerable changes which the surface tension of water undergoes when covered with a film of oil of the critical thickness. It is a very simple experiment and very effective. Therefore it is particularly interesting to know what thickness the film of oil must have at this remarkable phase.

II. THE THICKNESS AT MAXIMUM EXTENSION.

(1) *Experimental measures.*—Lord Rayleigh, in his admirable experiments of 1890, tried to find what is the minimum quantity of oil necessary to stop the movement of the camphor[2] and found an extremely small value, a thickness of about 1.6 μμ. In 1891 he published the letter of Mlle. Pockel, which we have just mentioned, and in the following year[3] showed the stopping of the movements of the camphor by a greasy body is due, as the law discovered by Mlle. Pockel led him to see, to a sudden fall in the surface tension of water when the grease layer has the right thickness. In 1899 he published a curve showing the relation between the surface tension and the quantity of oil[4] and showed that the proportion of oil when the surface

Fɪɢ 1.—Camphor boat (natural size); c, grain of camphor at the stern: m, mast amidships.

[1] See La Nature, April, 1888.

[2] Proceedings of the Royal Society, 47, Mar. 27, 1890. A French translation of the article will be found in Conférences et allocutions de Sir William Thomson (Lord Rayleigh), translated by Lugol (1893), p. 48.

[3] Philosophical Magazine, 33, p. 366, 1892.

[4] Philosophical Magazine, 47 and 48, 1899. In obtaining this remarkable curve, Lord Rayleigh appears to have supposed implicitly that the oil on the water always forms a continuous and homogeneous film, even when its surface is much diminished; for example when he gets the quotient of the weight of oil by the surface occupied. This is proper only when the diminishing of the surface is small, say in the ratio of 1 to 1.3. Beyond this limit this process is in error, for the surface begins to assume a globular form, finally becoming a veritable mass of foam. We will speak of this later on.

tension of the water begins to fall is about one-half that at which the camphor movements stopped. The thickness is therefore 1.6/2 or 0.8 μμ. But Lord Rayleigh gives it as simply 1 μμ.

We may obtain a yet greater precision by a method using drops of a standard solution of oil in a volatile solvent. I prepare a standard solution of oil in pure benzole. I use a solution containing exactly 1 cu. cm. of pure oleine (trioleate of glycerin) per 1,000 cu. cm. of benzole and a pipette giving 50 drops of this solution per cubic centimeter. Thus a drop contains $\frac{1}{50000}$ of a cubic centimeter of oil, and I place two of these drops upon the water. As soon as they touch the water, the drops spread over the whole surface; the evaporation of the benzole is almost instantaneous and leaves a residue of oleine equal to $\frac{2}{50000}$ or 400×10^{-7} cu. cm. Earlier measures showed me that this quantity of oil could not cover all the surface of the tray
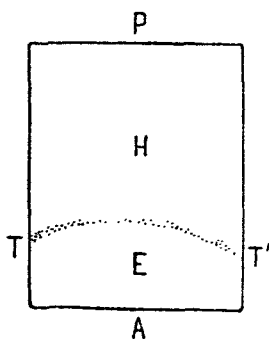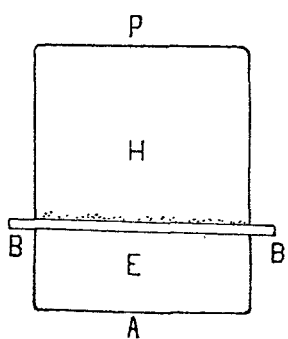
Fig. 2.   Fig. 3.

FIGS. 2, 3.—Arrangement for measuring the limiting thickness of a film of oil; H, film of oil; E, free water; TT', barrier of powdered talc; BB'', band of paper.

(625 sq. cm.). I blow upon it to gather the invisible film of oil at the farther end of the tray and then scatter upon the nearer end a light veil of powder with the sieve. The talc thus falls upon the free surface of water E (fig. 2); it scatters, carried by my blowing, but you see it stops abruptly along the barrier TT', which though invisible was sharp, and marks the edge of the oil film H. The stoppage is of striking sharpness.

I now apply to the portion of water uncovered with oil a band of paper BB' (fig. 3), in order to have a straight capillary border. I now make this barrier approach gently the border of talc which straightens, as is indicated in the figure.[1] If the barrier is moved a little farther, the talc grains just at the limit of the oil, and more or less distant from each other because they are slightly oily, we see

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[1] It is yet better to collect the talc scattered upon the free surface by the band of paper itself.

BOAT EN ROUTE IN BLACK TRAY ON WATER POWDERED WITH TALC.

A large wake of camphored water free from talc is very visible at the rear of the boat. The operator contracts or expands the free surface by changing the position of the strip of paper placed across the tray

undergo an abrupt closing up between the oil and the paper. Retreat the barrier, and all at once the same grains become free, again floating freely side by side. By means of these sudden changes and by moving the paper slightly back and forth, I can accurately, within a few millimeters, find the limit at which the oil is just slightly contracted, that is at the place where there is the first appearance of change in the tension. At this place I make my measure, determining once for all by my double decimeter rule the length of the film of oil.

(2) *Results.*—We thus get the area of the mean surface covered by the film. In the experiment made the 18th of April, 1912, it was 363.71 square centimeters. Now, this was produced by two drops of the oil solution; that is, by 400×10^{-7} cubic centimeters of oil. The thickness of the film was therefore:

$$\frac{V}{S} = \frac{400 \times 10^{-7}}{363.71} = 1.10 \ \mu\mu$$

with an approximation between 1.04 and 1.15 $\mu\mu$.

We can then state from this that the thinnest film of oil which can exist upon water is one and one-tenth millionths of a millimeter. This thickness, almost identical with that found by Lord Rayleigh, is remarkably small. A simple comparison will give us a better idea of it.

Let us imagine a film of this thickness covering a globe 50 centimeters in diameter; let us enlarge in thought this globe until it has the actual dimensions of our earth. The film enlarged in the same proportion will acquire a thickness of only 26 millimeters, while the paper which covers the globe and upon which the world map was made will increase from its original thickness of 0.1 millimeter to 24 kilometers!

(3) *Comparison with molecular dimensions.*—But we may make better comparisons. In the molecular theory, the thinnest film of any substance which can exist is evidently made of a single layer of molecules; for it is impossible to conceive of a film thinner than a molecule except through the deformation or destruction of the molecule itself.

We possess to-day very numerous and exact determinations of the Avogadro constant, allowing us to calculate molecular dimensions. We have made the calculation for oil, or rather for the trioleate of glycerin. Using Perrin's value for Avogadro's constant, we found 1.13 $\mu\mu$ for the molecular diameter. The theoretical value of the diameter of a molecule thus calculated is practically identical with 1.10 $\mu\mu$, the experimentally measured thickness of an oil film at its maximum extension. The difference is only in the hundredths of a micron.

We know therefore that a film of oil at its maximum extension is formed of only a single layer of molecules.[1] This remarkable fact is true of other films than those of oil, nor is it limited to liquid films. I have found it to be equally true for various solid substances, with this difference: it is the solid state itself which disappears at the critical thickness and not the surface tension, as with liquids.[2] I therefore derive this general conclusion: the characteristic mechanical properties corresponding to certain states of a body, the surface tension of a liquid or the rigidity of a solid, persist almost intact down to molecular thicknesses, disappearing abruptly the minute we go further.

This fact has a general significance which we should appreciate. For the present, however, we will be content in seeing a new and direct demonstration of the discontinuity of matter and the reality of molecules; it is indeed a new method allowing us to measure the dimensions of molecules with a precision comparable with that of the best methods we have.

III. THE EVOLUTION OF LARGE DROPS OF OIL UPON WATER.

Instead of placing upon the water a very minute trace of oil, let us put there an ordinary drop of one to three hundredths of a cubic centimeter. We will now watch a series of phenomena as interesting as what we have just seen. Scarcely does the drop touch the water when it spreads out and covers the whole surface. But the film, of course, is very thick. It is hundreds of molecules thick and clearly visible, because it reflects light better than does water. Generally we see interference colors, at least at one phase of its extension. But this phase is always fugitive, especially with nondrying and fresh oils and when the surface of the water is very clean. This is the case with the present film.[3] The evolution of a film lasts but 10 to 15 seconds; indeed the principal phases take place in the first 3 seconds. However, on water already oily, the formation is very much retarded and the film appears with a sharp circular border, as in plate 7. Soon its brilliant surface is pierced with black, circular spots looking like holes, where the water appears as if free from oil. These spots, more or less numerous according to the kind of oil, gradually grow in size, and each one is finally surrounded by a band of small droplets similar to pearls (pl. 3).

The first of these spots appears near the edge of the film, where it is thinner than at the center. They grow very rapidly and soon run together. The spots over the rest of the film subsequently behave in

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[1] Lord Rayleigh in the research cited above discussed this question, but the knowledge then of the value of Avogadro's constant was not so accurate.

[2] Devaux, l. c., 1904.

[3] The process of fixation of these films is peculiar and has been described in a special communication (l. c., Oct., 1912).
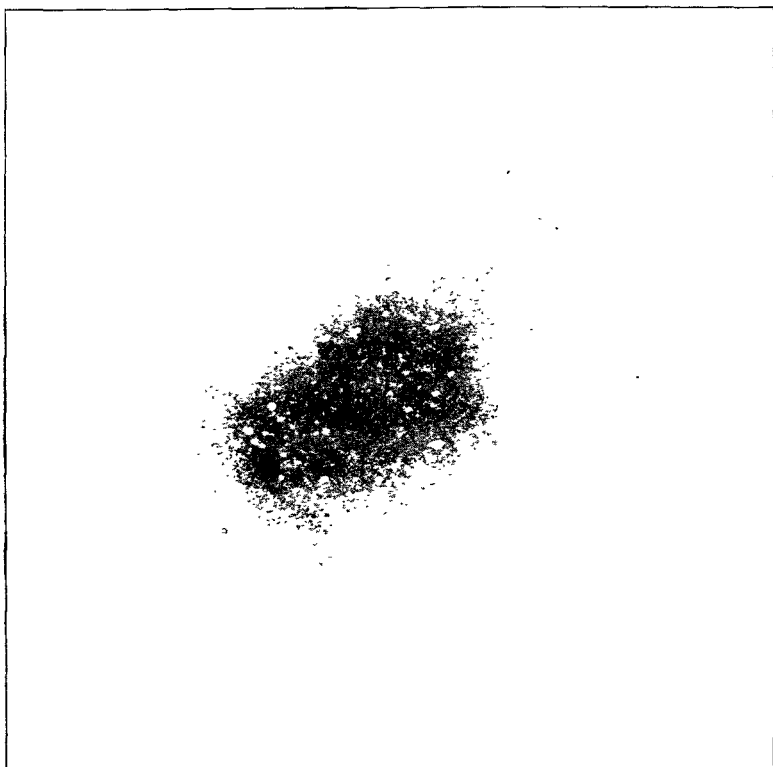
FILM OF OLIVE OIL AT THE BEGINNING OF ITS EVOLUTION UPON PURE WATER
(LESS THAN ONE SECOND AFTER THE DEPOSITION OF THE DROP).

The center is thick (rings and interference colors) the border thin (brown of the first
order, 100 _m_, then paler and paler white) The film is, however, already pierced with
circular holes, yet small and rare at the center, large and fused together at the edge.
There are fine droplets at the edge.

PLATE 3.
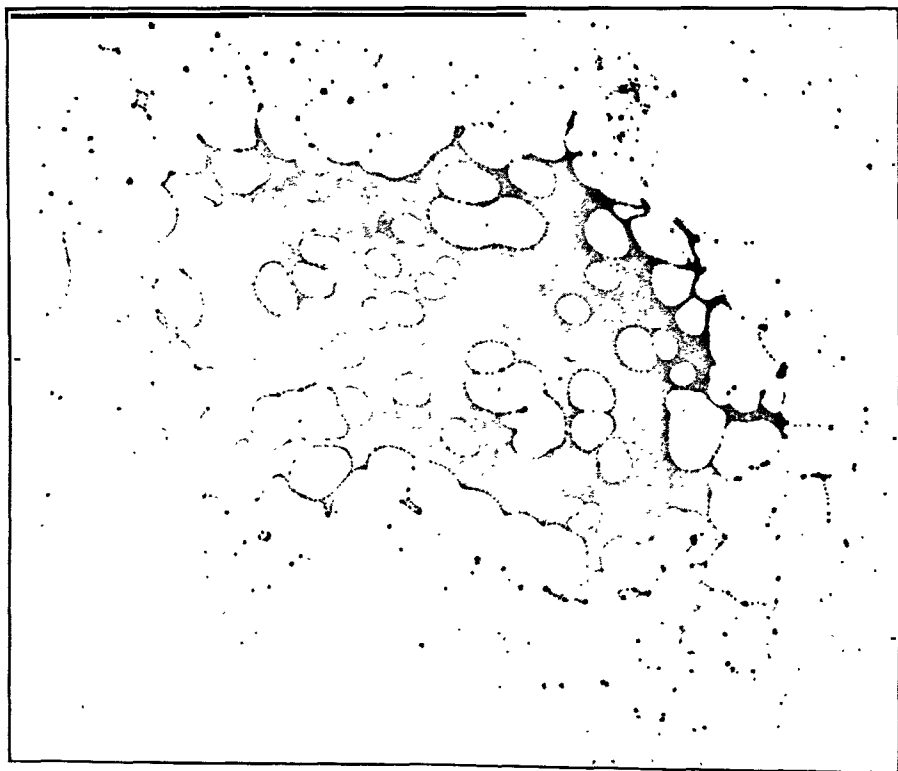
FILM COMPLETELY EXTENDED, AGE ABOUT TWO SECONDS.

Its spread has reached the phase when first-order tints appear. A general shrinkage is taking place everywhere. The central black spots have increased in size and fused together; their borders are much broken up and are surrounded by various-sized droplets.

the same way (pl. 4), so that finally the film is changed into groups of droplets scattered over the surface of the water, which reappears as if free from oil, and uniformly dark (pl. 5).

It is evident, however, that the surface of the water is yet covered between the globules by a very thin film of oil; and the persistence of this final phase shows that it remains in this discontinuous condition because the oil on the water is almost in static equilibrium. It is therefore necessary to distinguish two phases in the development of an oil film—the evolutionary phase, always fugitive, and the final static phase.

IV. THE STATIC PHASE OF OIL UPON WATER.

Let us consider especially this last phase, that of a very thin, continuous film extended over the surface of the water and studded or not with globules or disks. We will begin by establishing an important fact: the thickness of this continuous film depends upon the existence and dimensions of the globules. Because we find that when a film with minute globules exists beside one with great ones, the first always contracts at the cost of the second. Since, therefore, the tension is stronger in the former, we must conclude that the film with minute globules is the thinner.

With regard to the thickness of thin films, we are then led to distinguish four cases: the maximum and minimum thickness of films without globules; the maximum and minimum thickness of films with globules. Practically these reduce to three cases, since the maximum thickness of a film without globules is necessarily the same as the minimum thickness of one with globules.

(1) MINIMUM THICKNESS OF FILM WITHOUT GLOBULES.

We have already measured this thickness since it occurs in a film at its maximum extension and it is about 1.10 $\mu\mu$.

(2) MAXIMUM THICKNESS OF A FILM WITHOUT OR THE MINIMUM THICKNESS OF ONE WITH GLOBULES.

(*a*) Principle used in measuring films of a thickness greater than that at the minimum: While the minimum thickness of oil films is easy to obtain and even to measure, because of the sudden and considerable change in the surface tension for small variations in thickness, this is not the case for thicker films; for when we pass the critical thickness, the surface tension scarcely alters even for very great variations in the thickness of the film. It is therefore much easier to measure a film at its minimum thickness than at a greater thickness.

However, since it is always possible, by enlarging the film, to pass from a thicker to a thinner film, this difficulty can be avoided.

We can then in any case choose an oil film without globules having the desired thickness, isolate a portion of the surface, S, then enlarge this to its greatest extension, S'. It will then have its minimum thickness. The ratio S'/S will be the ratio of the two thicknesses. Since the minimum thickness is known, we obtain the other thickness by multiplying by this ratio.

(b) Experimental procedure: In order to determine the greatest thickness of an oil film without globules, I proceed as follows. By means of a glass fiber, I place upon the water of my tray a drop of several tenths of a cubic millimeter. It expands into a film which contracts very quickly into a multitude of little droplets scattered over a black film. I now place a sheet of paper over the greater part of the surface and move it very slowly toward me. Immediately we see the globules over the rest of the surface grow into brilliant disks which finally break up into smaller drops. Repeating this partial wiping away several times, the globules one by one disappear, each momentarily becoming a disk, multicolored or of brilliant white. Finally the whole surface of the water appears black. But there are still very small droplets which may be made evident by slight enlargements made by jerking the dish. Each one gives a flash of light and then disappears. The final phase of the phenomenon requires acute observation, especially for some oils which produce particularly fine globules. In such cases I scatter a light veil of talc powder on the film, then extend the film slightly and at once we see the talc thrown out in little circles about each minute globule.

(c) Results: The following table shows results obtained by the process just described. It gives the ratio between the greatest and least thickness we can have with films without globules.

Trioleine	1. 32	1. 27	1. 28
Olive oil	1. 27	1. 21	1. 22
Linseed oil	1. 18	1. 15	
Nut oil	1. 18		
Cod-liver oil	1. 16		
Sheeps-foot oil	1. 16		
Castor oil	1. 53		

The ratio of the maximum to the minimum thickness for an oil film without globules varies a little from oil to oil, but it is always less than two. It is usually very close to unity, so that a film extended over water can have a maximum thickness but little superior to its minimum thickness. We may otherwise state this. A film thicker than one molecule can not exist without nearly all the excess of oil forming into globules.

(d) The formation of foam in a very shrunken oil film: The last experiment explains a very curious and interesting fact. If we reduce an oil film from its maximum extension so as to diminish its surface to one-tenth or one-twentieth of its original area the film
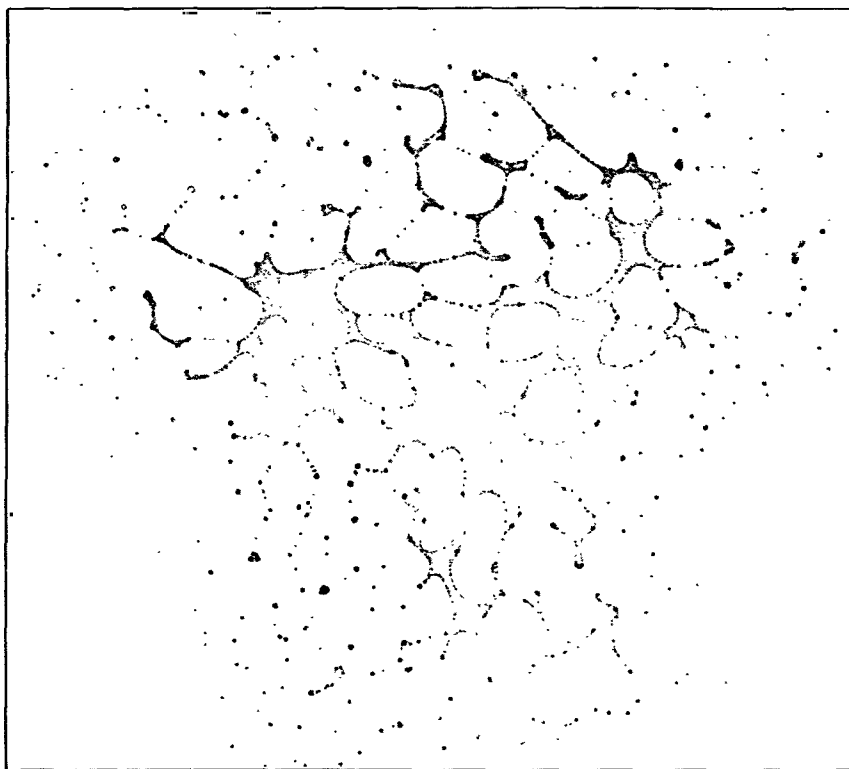
VERY ADVANCED STAGE IN THE BREAKING UP AND CONTRACTION OF AN OIL FILM
BY THE FUSING OF THE BLACK FILM AND DROPLETS INTO DROPS OF VARIOUS
SIZES.

This film is about three seconds old
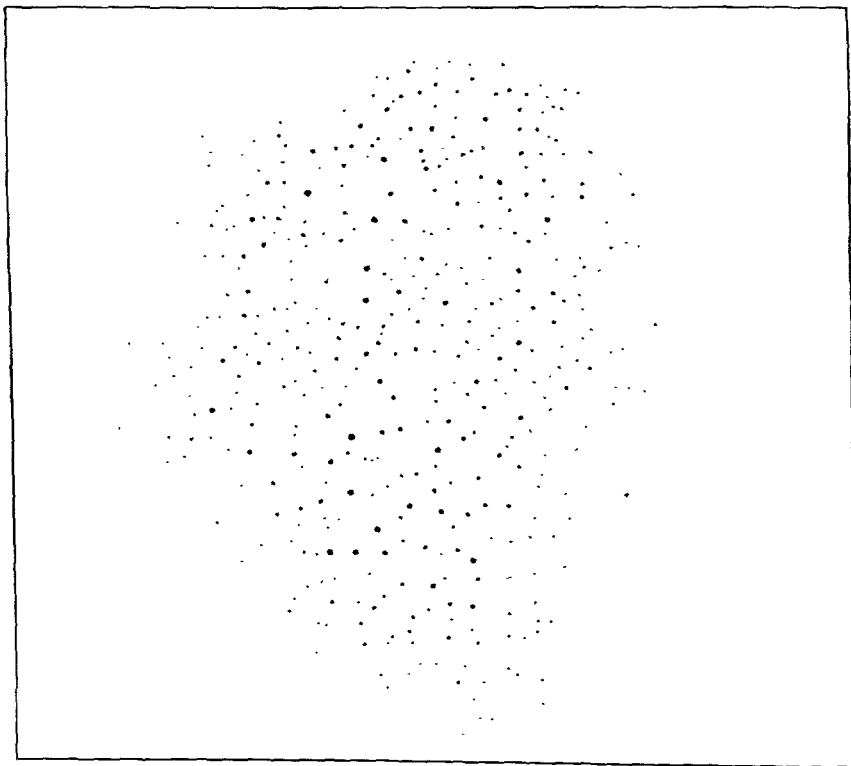
FINAL NEARLY (¹) STABLE STATE REACHED AFTER 10 TO 15 SECONDS.

The oil film seems reduced to a cloud of fine droplets scattered over the water.   In reality, a very
thin continuous oil film exists between the droplets.   The figure of equilibrium of oil on water
is therefore discontinuous.   (¹) I say 'nearly' because the drops are still undergoing small
displacements: they are approaching each other and fusing into larger droplets.   This fusion
is often hindered by an increasing viscosity, leading to an apparent solidification of the oil in
contact with the air

loses its bright aspect, becoming leaden and as if covered with an-exceedingly fine foam. Microscopic examination assures us that the oil has changed into a multitude of droplets of various sizes, 10 μ, 5 μ, 1 μ, and less. Working in the sunlight, I have seen the foam appear before the film has been reduced to one-half its maximum extension.

This is a new and direct proof of what we have just learned, that as soon as an oil film is so much reduced in surface that it is more than one molecule thick, nearly all the excess of oil forms into globules.

(e) Variation of molecular distances: This extraordinary fact gives a new and interesting insight into the field of molecular action. It shows particularly that the forces which stretch out these films of liquids are due almost wholly to a single layer of molecules and that the surface layer. It is evident further that a film, if it is uniform, must be greater than one and less than two molecules in thickness. Now, everything indicates that a film is really uniform and homogeneous, since the least variation in its thickness gives rise to considerable differences of tensions which tend to reestablish everywhere a perfect homogeneity, and especially the equality of molecular distances. The difference between the states of least and greatest extension can be dependent then only on the distances between the molecules; if they are compact in the first case, they can not be so in the second. At any rate, that is the interpretation given by M. Brillouin in a discussion which followed my communication.[1] The distance apart of the molecules in such films will be inversely as the square root of the surface. Accordingly, the square roots of the preceding ratios give the relative molecular distances. This ratio ranges between 1.1 and 1.2.

It follows that as soon as the molecules of a mono-molecular oil film are separated by from 1.1 to 1.2 their normal distances, they lose all power of lowering the surface tension of water. Conversely, as soon as the molecules are brought together, so that they are separated by 1.1 to 1.2 of their normal distances, they cause an abrupt and considerable fall in the surface tension of the water, making it practically the same as if it were a large body of oil. For beyond this limit the oil gathers into globules.

(f) Correction to the value of the normal molecular distance: The measure of the molecular distance 1.10 μμ, given above, corresponds to films at their greatest extension. The true distance in normal oil will be somewhat smaller, say 1.10/1.1 to 1.10/1.2 or 1.10 to 0.92 μμ. This corrected distance differs decidedly from the theoretical value, 1.13 μμ, deduced from the measures of Perrin. Some day we will examine the cause of this difference.

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[1] Meeting of the Société de Physique, May 3, 1912.

(3) MAXIMUM THICKNESS WITH GLOBULES.

(*a*) Method of measurement: This measurement is especially diffi-cult. After various attempts, I came to the conclusion that here the only certain method was to proceed by the extension of the film as in the previous case. In order to determine the maximum thickness, I isolate portions of great black spots (4.5 cm. in diameter) which have appeared very slowly from a thick sheet of oil (pl. 6). Then, first lightly powdering the surface, I enlarge it to its maximum extension. This operation is often hindered by the existence of very minute globules. In an instance where the globules were absent I noted that the maximum extension was obtained by about doubling the surface. It certainly was not tripled. We may say, then, that a film of oil at its greatest thickness, when the excess of oil has formed into disks in contact with it, is only about twice its least thickness.

In other words, no continuous film will be stable on water when its thickness is greater than two molecules, whatever be the thickness of the masses of oil in contact with it. It will be necessary to await new measures before we truly know whether these films have a real thickness analogous to the maximum thickness without globules. That is, whether they are not formed of a layer of single molecules packed as closely together as possible.

(*b*) Discontinuity maximum: We are now in the presence of the maximum of the discontinuity of oil films upon water. We may easily have upon the water disks a millimeter or more in thickness. I have noted, for instance, that a cubic centimeter of olive oil placed upon water already heavily oiled forms a disk 30 mm. in diameter and having an area about 7 square cm. Its mean thickness is there-fore greater than 1 mm. and it is certainly 2 mm. thick at its central part. Despite this thickness, the disk is surrounded by water on all sides, kept in stable equilibrium by an absolutely invisible film of oil having a thickness one-millionth of that of the disk.

A simple comparison will show how peculiar is this discontinuous equilibrium of oil on water: Let us imagine our film enlarged one-half a million times; then our oil film at its maximum thickness would be 1 mm. thick, and it carries instable equilibrium masses of oil whose thickness can reach and even surpass 1 kilometer (1,000,000 mm.)!

(*c*) Comparison with the black film of soap bubbles: I have already, in calling attention to the evolution of a thick film of oil newly formed upon water, spoken of the constant appearance of black circles which grow larger and larger and merge finally into a continuous surface dotted with globules. It is odd that physicists

have not been struck long since with the resemblance between these "holes" in the oil films and the black spots of soap bubbles. The mode of sudden appearance, the circular form, size, and progressive enlargement are very similar, and each hole is really occupied by an oil film whose thickness is comparable with that of the black spot of the soap bubble.

The holes in the oil film are, it is true, always more numerous, and further, they finally become surrounded with droplets and then flow together (pls. 3 and 4). In reality, soap bubbles often show several simultaneous black spots, especially just before rupture. Further, and which is of special interest, Herbert Stansfield[1] has called attention to black spots in soap bubbles accompanied by collars of disks and granules which correspond to what occurs with oil films, only, since the soap bubbles are never horizontal, gravity necessarily pulls the thick portions away from where they appear. The confluence of the spots is not then peculiar to oil films.

The phenomena in the two cases are the same, the differences arising from the changed conditions under which the films are formed, an independent and two-faced skin in the case of a soap bubble, a skin adherent to and supported by water in the case of the oil film. Accordingly, the study of the evolution of oil films throws light upon the final stages through which a soap bubble goes when it does not break. It becomes reduced to a black, very thin film, dotted with thick portions, either circular disks or droplets.

Further, similar, very large, black spots have been obtained in the films of soap bubbles by Reynold and Rucker[2] in their beautiful researches made between 1877 and 1893. Upon these films they determine the thickness of the black spots which were all found sensibly equal and equal to about 12 $\mu\mu$. Johannot[3] later showed that films could exist having a thickness one-half as great, or 6 $\mu\mu$.

We can now compare the thicknesses of oil and soap bubble films. In both instances we have black films formed from much thicker ones.

Black films of oil with a maximum thickness of 2 to 3 $\mu\mu$.

Black films of soap bubbles, maximum thickness of 6 to 12 $\mu\mu$.

These thicknesses are of the same order. Oil films are certainly always at least one-half as thin as the thinnest soap-bubble films. This important difference must be due to the fact that in the case of oil films on water there is only one free surface.

[1] Proceedings of the Royal Society, 1906, p. 311.

[2] A. W. Reynold and A. W. Rucker, Proc. Roy. Soc. of London, 1877; Phil. Trans. ditto, pt. 2, 1881, 1883; Phil. Mag., vol. 19, 1885; Phil. Trans. Roy. Soc. of London, II, 1886; Wied. Ann., vol. 44, 1891; Phil. Trans. Roy. Soc. of London, vol. 184, 1895.

[3] Johannot, Phil. Mag., vol. 47, 1899.

TABLE OF RESULTS.

· The following table gives a summary of the previous results and allows us to make useful comparisons.

THEORETICAL REPRESENTATION OF BLACK FILMS AND OF MOLECULES.

Greatest and least thicknesses of stable oil films expanded upon water. The thicknesses are multiplied by one million (1 mm. represents 1 $\mu\mu$.)

▬▬▬▬▬▬	1.13 $\mu\mu$	Theoretical size of oil molecules (trioleate of glycerine),[1] calculated from Perrin's data.
▬▬▬▬▬	1.10 $\mu\mu$	Minimum thickness of a stable oil film found experimentally.
▬▬▬▬	1.15 to 1.53 $\mu\mu$	Maximum thickness of a stable film without globules, or the minimum thickness of a film with globules, found experimentally. } Black spot of oil films.
▬▬▬▬	2 to 3 $\mu\mu$	Maximum thickness of a film in stable equilibrium with great globules or with masses of oil of 1 mm. or greater in thickness.
███	6 $\mu\mu$	1st minimum thickness of film of soap-bubbles. } Black spot of soap-bubble films.
███	12 $\mu\mu$	2nd minimum thickness of films of soap-bubbles or maximum thickness of the black spot.

V. OIL FILMS ON MERCURY.

Oil placed on mercury shows very similar results to those obtained upon water.[2]   There is still a very sharp limit to the extension, and the thickness of the films at the limits is sensibly the same.   When the oil is abundant enough, it forms a thick colored film which grows rapidly with the production of black spots surrounded with globules (pl. 7) and finally becomes a very thin film dotted with droplets. Other liquids (sulphuric acid, soap water, distilled water) give upon mercury analogous growths.   We have therefore here a very general class of phenomena.[3]

VI. CONCLUSIONS.

We see now that a concept which at first seemed chimerical—that is, the reduction of substances to perfectly homogeneous films only one molecule in thickness—has become an experimental reality.   And in-

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[1] See Devaux, l. c., November, 1912.
[2] Devaux, Journal de Physique, November, 1912.
[3] Karl Fischer in his inaugural dissertation (Die geringste Dicke von Flüssigkeitschichten, München, 1896), studied the extension of two oils and other liquids upon mercury. He gives numerous measures of the thickness of films before their rupture.   The thinnest had thicknesses less than 3 $\mu\mu$ (rapeseed oil) and 1 $\mu\mu$ (sulphuric acid).

PLATE 6.

GREAT NETWORK OF OLIVE OIL AS GENERALLY FORMED AFTER A LONG TIME BY A VERY THICK FILM.

The openings in the network are composed of great black fused films. Here and there are droplets.

PLATE 7.
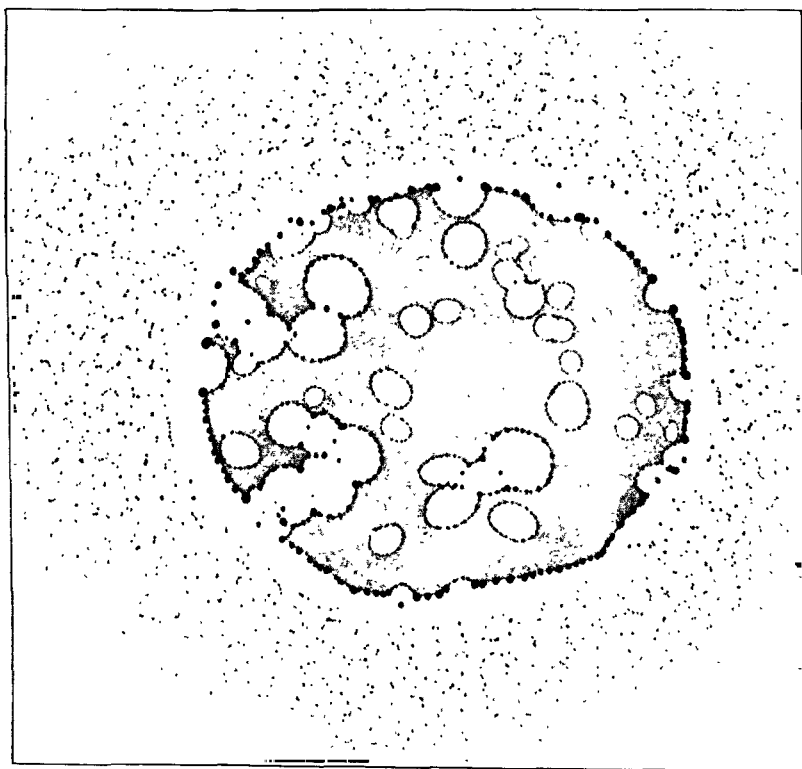
FILM OF OLEIC ACID UPON MERCURY. COLOR, VIOLET-ROSE (140 μμ).

The surface of the mercury had already received a drop of acid which had entirely contracted into droplets. The new drop expanded very slowly with clearly defined thick borders. These borders have already been transformed into chaplets of great drops such as are always found about the black spots which appear at various moments in the expansion of a film.

deed these phenomena work spontaneously and are visible to you all whenever a drop of grease falls upon the water in one of the ordinary plates from which you eat, so that nothing is more common and banal than these extremely thin films.

The formation and stability of these films are automatic. The stability is so great that it is possible, without breaking the film, to distend it—that is, to separate progressively the molecules—until their reciprocal action is entirely destroyed, an operation which we could not perform upon liquids in bulk without leading immediately to rupture.

With our films, however, this is a most simple operation and always successful; it is only necessary to increase the free surface occupied by the film upon the water or the mercury. Thus we have become acquainted with the fundamental fact that the extension of the oil film is limited. As soon as the molecules are separated by a distance greater by one to several tenths of their normal distance they lose all reciprocal action, for they no longer diminish the surface tension [1] of the water. We have called this phase the maximum extension. Conversely it suffices to bring them together, by contracting the surface slightly, in order to see the effect of the oil upon the surface tension of the water reappear and increase rapidly, so that the tension passes rapidly from that of pure water to nearly that of oil.

These facts allow us to enter directly the experimental study of the field of molecular action.[2] They allow us to catch a glimpse of other mysteries to be discovered, other marvels to contemplate, and to delve into that domain of invisible elements of which visible matter is composed.

The little drop of oil has much more to show us. Who knows, indeed, but that it will bring us before long phenomena of the greatest importance, yet which at present we can not foresee?

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[1] A curious exception is found in oleic acid and in soap, the molecules of which when stretched over water can be separated some ten times the molecular distance. Devaux, l. c., 1904.

[2] M. Brillouin so stated in the appreciation which this professor of the Collège de France gave upon my researches at a meeting of the Société de Physique on the 3d of May, 1912.

WATER AND VOLCANIC ACTIVITY.[1]

By Arthur L. Day and E. S. Shepherd.[2]

[With 11 plates.]

GREEN'S VIEW THAT THE KILAUEA EMANATION IS ANHYDROUS.

In a book,[3] now little known and rare, William Lowthian Green, a distinguished Englishman, long in the service of the native government of the Hawaiian Islands, writes as follows:

What we mainly wish to contend for and to impress upon geologists—for reconsideration, at least—is. that it may be a mistake to assert, as is so often done in the most positive manner, that water and steam are inseparably connected with volcanic action. On the contrary it would appear that elastic vapors have nothing to do with the liquidity of the Hawaiian basic lavas, and that as a matter of fact they do not seem to come up with them from below. whilst the basic minerals themselves give no indications in the main eruptions, of having been in contact with water. highly susceptible as they are, to such an influence.

Mr. Green was not only a keen observer of the manner of operation of the physical forces which participate in the volcanic activity to be seen in the Hawaiian Islands, but his opportunities for studying such phenomena were quite exceptional. His conclusion, supported as it was by many facts of observation, has therefore demanded, and indeed has received, consideration at the hands of geologists generally, although until very lately no one has been willing to consider it as having any application to volcanoes outside Hawaii.

BRUN MAINTAINS THE SAME VIEW.

More recently Albert Brun, a chemist of Geneva, Switzerland, has offered data [4] (apparently without knowing the work of Green) gathered from a great number of active volcanoes with intent to prove by analysis of the gases which he collected that water plays

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no part in volcanic activity. His words are as follows (p. 249, following a detailed statement of reasons which will be considered below) :

Il est donc *parfaitement certain que le volcan paroxysmal n'exhale pas d'eau. La preuve est faite.* Le grand *panache blanc* est composé de particules *solides* et *anhydres.*

Il faut donc *que la théorie aqueuse disparaisse de la science.*

(The italics are Brun's.)

Except for these two conspicuous instances, students of vulcanism have generally concluded[1] that water is usually if not always the chief agent in volcanic activity.

It is not our purpose to discuss this question at this time except in so far as it may find application in the volcano Kilauea on the Island of Hawaii, but this volcano provided all of the material for Green's discussion and a very essential portion of that offered by Brun. It will therefore be of interest to record some observations made in the course of an extended study of this volcano by the writers during the summers of 1911 and 1912. The purpose of these studies is to obtain definite information about the character of the chemical reactions which take place in an active volcano, and in particular to determine the rôle played by the gaseous components, which are very important factors in both its chemical and physical activities. In many studies of volcanoes the gases have been allowed to escape entirely, while in others they were not captured until the nature of the components was so much altered by oxidation or otherwise that their identification, to say nothing of the determination of their relative proportions and the character of the equilibrium existing between them, has remained uncertain. On these broader questions, which are laboratory problems, most of the work still remains to be done. It is, however, quite possible to offer evidence on the participation of water and of some of the other volatile ingredients in the activity of Kilauea in advance of this study, which may require some years before all the questions which have been raised are satisfactorily elucidated.

DISCUSSION OF THE OBSERVATIONS OF GREEN AND BRUN.

First let us review somewhat briefly the observations which led Green and Brun to the same novel conclusion, that water has no part in the volcanic activity of Kilauea. In the case of Green such a

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[1] G. Poulett Scrope : " Volcanoes," London, 1872. John W. Judd : " Volcanoes, what they are and what they teach," London, 1881. James D. Dana : " Characteristics of volcanoes." New York, 1891. A. Geikie : " Textbook of geology," vol. 1, London, 1903. S. Arrhenius : " Lehrbuch der Cosmischen Physik," Leipzig, 1903. It should perhaps be added that some have expressed the opinion that the importance of water has been overestimated, without explicit denial of its participation in volcanic activity. (See, for example, J. G. Bornemann : " Ueber Schlakenkegel und Laven, ein Beitrag zur Lehre vom Vulkanismus," Jahrb. d. Kgl. pr. geol. Landesanstalt, u. Bergakad, 1887, p. 230.)

review is not altogether easy. His reasoning is based on deductions from many phenomena, such as appeal to an observer on the ground; great lava streams without a trace of vapor rising from them; a condition of great activity in the lava pit of Halemaumau (the only portion of the Kilauea Volcano now continuously active), with hardly a trace of any cloud above it; a rather conspicuous difference in character between the Halemaumau cloud (when there is one) and the clouds which arise from numerous steam cracks in the country round about, etc. Perhaps the chief factor which clinched his conclusion was the fact (which we also observed) that there are times when a magnificent cloud rises from the active basin, separated by but a day or two from periods when practically no cloud can be seen, and this with no apparent change either in the character or amount of activity visible in the basin. He therefore concluded that if steam was the moving force, and if the great white cloud was the manifestation of that fact, its presence must be expected on one day as much as on another in which the same gas and lava conditions appeared to prevail.

He was also able to discover no diminution in the liquidity of the lava, either in the crater or in the great lava streams during those periods when no cloud was seen, and therefore no casual connection between the presence of the gases and fluidity of the lava.

Had it occurred to Green to try to remelt some of the solidified lava after the gases had escaped, this last puzzling question would have been clearer to him, for the crudest effort would at once have revealed the fact, which since then has often been noted, that these lavas, when reheated to the temperature prevailing in the lava lake before solidification, remain quite rigid—the characteristic fluidity has departed with the escaping gases.

Brun's statement of his observations at Kilauea is more explicit. In particular he offers six definite reasons for believing that steam is not present either in the lava basin or in the cloud above it. They are these:

(1) The cloud arising from the crater does not evaporate in the sun as do the clouds arising from neighboring cracks after a rain, but can be seen floating majestically away often for 20 miles or more.

(2) No rainbow or other optical phenomena can be detected in the cloud arising from the crater, although rainbows are abundant enough in the vicinity under appropriate conditions.

(3) If the cloud were of steam emerging from white-hot lava, there should be an interval of a few feet between the point of emergence and the beginning of condensation (like the dark space immediately in front of the spout of a steaming teakettle) in which the steam should be invisible. No such dark space could be seen.

(4) As the cloud rises past the rim of the crater on the leeward side, the walls about the crater, being comparatively cold, should be wet with the condensed vapor, whereas in fact these walls remain quite dry.

(5) A train of glass tubes was lowered over the rim of the crater for a few yards on the side where the cloud was emerging, and through these tubes (some 250 feet distant from the nearest liquid lava, it may be remarked) air and the vapors carried by it were pumped for several minutes, but no trace of condensed moisture appeared on the inside walls of the tubes. Examination with a hand lens revealed the fact that the tube walls were quite thickly covered with crystallized salts, some of which were stated to be hydrates or to be hygroscopic, but this was deemed to be due to original moisture (!) carried on the tube wall before the beginning of the experiment. No analyses of the gases or of the solid salts are given.

(6) A dew-point hygrometer carried along the rim through the smoke cloud showed a lower humidity within the cloud than in the clear air just outside of it.

Before proceeding to recount our own experience with these phenomena, it may be as well to express our belief that nearly all of these observations, both of Green and Brun, may be perfectly true as recounted above, and still offer no proof that the volcano exhales no water vapor.

THE EXPLANATION OF THE VOLCANO CLOUD.

Green's observation that the great white cloud appears but intermittently may be explained by a somewhat closer observation of the conditions of formation of the cloud without assumptions of any kind about its possible water content. For example, we noted, during several months of constant observation, that the visible cloud does not rise directly from the surface of the liquid lava, but rather from cracks in the inclosing banks,[1] shattered, as they always are, by alternations of heat and cold as the liquid lava rises and falls in

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[1] Cf. plates 6, 7, 8, and 11.

Observations confirmatory of the conclusion that the smoke cloud when present does not rise from the liquid lava, but from the shattered floor and talus surrounding the basin, have been recorded by other writers.

For example, Prof. W. T. Brigham, director of the Bishop Museum, Honolulu, who for 50 years has been one of the most careful observers of volcanic phenomena in the Island of Hawaii, writes as follows: (Volcanoes of Kilauea and Mauna Loa on the Island of Hawaii, Honolulu, 1909) :

Page 28: " * * * It should be noticed how small the supply of steam in the active outpour of Kilauea really is."

Page 28: " When the pit is empty of molten lava, the smoke is often most abundant."

Legend to plate 45. " Lava pool below the rim of Halemaumau. * * * Little vapor rises from the portion which is active."

Legend to plate 50: " There is little escape of steam from the lake surface."

William Lowthian Green (Vestiges of the Molten Globe, vol. 2) writes (p. 170) : " Smoke, vapors, and gases seem to arise from the orifices of eruption and orifices in the neighborhood of molten lavas on Hawaii, and not from the lavas themselves."

the basin. When the lava is high enough to completely flood the floor of the basin, these cracks are closed and all the gases emitted emerge directly from the surface of the lava into the atmosphere and have the temperature appropriate to the surface of the liquid (1,000° to 1,200° centigrade). At this temperature the gases (sulphur and hydrogen, for example) burn promptly on contact with the oxygen of the air and remain nearly or quite invisible. A thin blue haze can sometimes be distinguished above a bursting bubble[1] when conditions are exceptionally favorable, but this haze is so thin that spectators watching for it from the rim will generally disagree about its existence.

This is the condition of no cloud (pl. 1) described by Green, and does not in the least suggest either a change in the composition or a diminution in the total quantity of the gases given off by the volcano.

When the lava level in the lake has fallen 10 or 20 feet (which is an almost daily occurrence and often takes place within an hour), only part of the gases set free come from the free surface of the lava, and considerable quantities now appear through the shattered floor surrounding the basin. The gases bubbling out from the lava basin remain as transparent as before and for the same reasons, but the gases appearing from the cracks in the floor and from the surrounding talus are now cooled in passing through the cracks to such an extent that they no longer burn on reaching the oxygen of the air. Free sulphur is then set free in considerable quantities, unburned; this we were able to collect without trouble, both at the point of emergence and on the crater rim. It is this finely divided free sulphur which is mainly responsible for the beautiful white cloud (pl. 2) above the crater and not crystalline chlorides, as supposed by Brun. In fact only a minute quantity of chlorine or its salts (less than 0.02 per cent) could be found in the emanations from the Kilauea basin during the period of our visit.

Our observation of the appearance and behavior of this cloud is therefore in full accord with the observations of both Green and Brun, so far as recorded, but there is nothing in the facts thus established to show whether the sulphur is accompanied by water vapor or not.

Herein is also to be found a sufficient explanation of Brun's observations—(1), (2), and (3), page 277, that the cloud when present does not evaporate after leaving the crater, that it gives no optical phenomena in sunlight, and that it is immediately visible as it emerges from the floor cracks and talus without a transparent zone separating the point of emergence from the visible cloud—results which would be expected if the cloud consisted only of steam, but not if it contains much sulphur.

[1] Cf. Frank A. Perret: "The circulatory system in the Halemaumau Lava Lake during the summer of 1911." Amer. Journ Sci. (4), vol. 35, 1913. p. 341.

The remainder of Brun's observations of the apparent absence of water vapor may find appropriate explanation in the fact that they were made in an unsaturated atmosphere (as shown by his elaborate records of the hygroscopic state of the air during his observations) at a distance of more than 250 feet from the point of emergence of the gases, and the further fact that the cloud not only carries sulphur, but two of its oxidation products, SO_2 and SO_3, both of which in these circumstances are effective drying agents. It may very well happen that water is given off in considerable amount by the volcano and yet remains invisible; for, in addition to the portion disappearing as vapor in the unsaturated atmosphere,[1] a considerable additional quantity will condense about the finely divided sulphur particles, serving as nuclei of condensation.

Furthermore, in our opinion, Brun's explanation of what he deemed to be crystals of hydrated salts in his vacuum tubes and in the pipe line through which his gases were pumped is a somewhat fortuitous one, and certainly leaves an element of reasonable doubt whether their presence was entirely due to moisture carried by the tubes themselves. The very care exercised by Brun would seem to make this unlikely except for the fact that it was offered by Brun himself. If it could be shown that these hydrous salts were regular inhabitants of the sulphur cloud, the comparative dryness of the cloud would also find ready explanation.

Brun's final contention (sec. 6, p. 278) that a dew-point hygrometer carried along the rim of the crater shows a lower humidity within the cloud than in the clear air immediately outside of it appears to be open to serious criticism from the physical side, although if one may judge by the space given to these observations in " L'Exhalaison Volcanique," this is the point which Brun himself regarded as the most convincing observation of all. It appears to be a matter of grave doubt whether the readings of a dew-point hygrometer in an atmosphere containing SO_2 and SO_3 have any significance whatsoever, in view of the well-known affinity of these compounds for water. The cloud could hardly be charged with better drying agents than these under the conditions described; it might, therefore, a priori, be expected to contain less free moisture than the adjacent atmosphere which does not contain these drying agents. Furthermore, the effect on the dew-point apparatus itself of exposure to the cloud contain-

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[1] Prof. J. P. Iddings, Prof. H. D. Gibbs, of the University of Manila, and several chemists from the Philippine Bureau of Science have observed gaseous emanations rising in great volume near the volcano Taal, which were found to contain large quantities of water and yet gave no trace of a cloud. (Unpublished records of the Bureau of Science, Manila, P. I.)

PLATE 1.
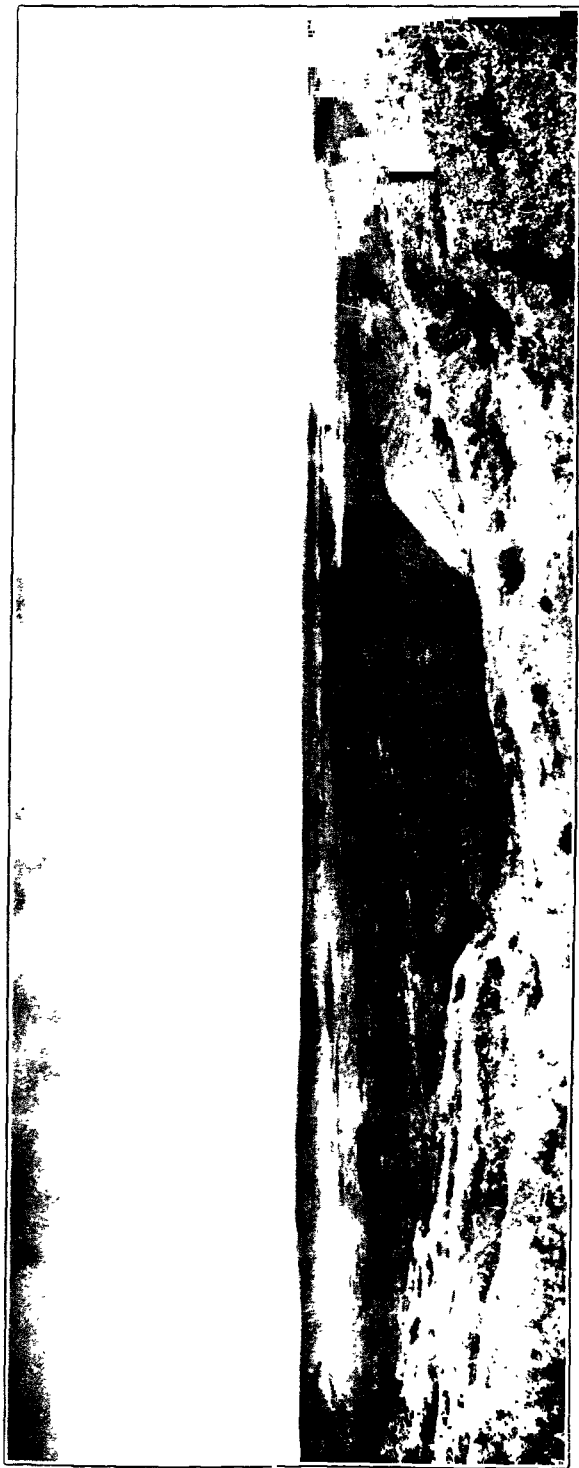
A PANORAMIC VIEW OF THE KILAUEA CRATER FROM UWEKAHUNA (JULY 7, 1912).

Showing the present active pit of Halemaumau free from smoke. The small clouds rise not from the active pit itself, but from the cracks surrounding the pit and are chiefly of steam.

PLATE 2.

PANORAMIC VIEW OF KILAUEA CRATER FROM THE VOLCANO HOUSE (JULY 31, 1912).

Showing the beautiful smoke cloud. Mauna Loa is seen in the distance at the right.

ing SO_2 and SO_3 may be a factor of considerable significance. The first reading of the instrument might well be approximately correct, but subsequent readings would surely all be subject to the effect of uncertain amounts of SO_2 and SO_3 carried by the instrument in consequence of the first exposure. This would have the effect of rendering all the subsequent readings of the series quite valueless as a measure of the water content either of the air or of the cloud.

In order to support the view that the atmosphere within the cloud containing SO_2 and SO_3 is necessarily drier than air which does not contain these substances, several measurements of dew points were made by us in an appropriate laboratory apparatus, of which the results will be found in the table below. The first column contains the dew point of air at varying degrees of saturation; the second column the dew point of the same air to which 1 per cent of SO_2 (air + 1 per cent SO_2 is still respirable) has been added. All observations are in duplicate.

Observations of dew points.

Air of random water content.	The same air + 1 per cent SO_2.	Difference.
°	°	°
7.2	6.4	−0.8
7.0	5.8	−1.2
19.2	18.1	−1.1
19.4	18.4	−0.9
20.4	17.5	−2.9
20.2	18.5	−1.7
21.6	19.7	−1.9
21.1	19.4	−1.7
21.5	19.0	−2.5
21.5	20.4	−1.1

Dew-point observations in the nature of the case can make no pretensions to high accuracy, but the effect of charging the air with a very small quantity of SO_2 is shown most convincingly. The effect of the addition of SO_3 would have been still greater than that of SO_2, since it forms H_2SO_4, a notable dehydrating agent; but this effect is somewhat more difficult to examine experimentally and so was not undertaken; indeed, it was unnecessary, in view of the fact that the point at issue is abundantly proved by the observations contained in the table above. Brun has therefore proved no more with his hygrometer measurements than that the great white cloud does not consist entirely of water vapor, but it is not possible to estimate the percentage of water contained in it from any figures based on dew-point determinations under the conditions which he describes.

From this evidence it appears clear that the observations of fact noted by both Green and Brun may for the most part be precisely as

described, and still the conclusion that water is not exhaled by the volcano Kilauea remain in doubt.[1]

AN ATTEMPT TO COLLECT THE VOLCANO GASES BEFORE THEY REACHED THE AIR.

Be that as it may, in our effort to obtain samples of the gaseous emanations from Kilauea for further study in this laboratory, it was a matter of very great importance to us to endeavor to establish the facts in the case without the aid of inferences of the character above outlined. We therefore entered on a long study of the habit of the volcano with the purpose of going down on the floor of the crater directly adjacent to the liquid lava, there to collect gases before they had come in contact with the air at all. In the interval between May 1, 1912, and January 1 following but two favorable opportunities for such an undertaking occurred, of both of which we endeavored to take advantage. On the first occasion (May 28, 1912) a column of liquid lava had worked its way up through the shattered floor adjacent to the large active basin and formed an active lava fountain there several feet in diameter. Through its own spattering this fountain quickly built for itself an inclosing wall or dike. When this dike had grown to a completely inclosing dome (pl. 3), the gases discharged by the fountain were free to escape only through narrow slits in the dome, and there they could be seen at night burning fitfully, with a pale blue sheet of flame, thereby demonstrating (1) an excess pressure within, and in consequence (2) that the gases released from the liquid lava first came in contact with the air on emerging from these cracks in the dome.

We accordingly made the somewhat difficult descent into the crater without mishap, and two crates, each containing 10 glass tubes of one-half liter capacity each, arranged in a continuous series, were then lowered down to us. To one end of this series of tubes a glass pipe line was attached, which led directly into one of the cracks of the dome (see pl. 4) through which the gas was escaping. The last link of the pipe line consisted of an iron tube extending into the dome about 12 inches. This iron pipe was also lined with glass up to the very mouth of the crack, so that, except for the 12 inches of iron pipe within the dome, the gases came in contact with no substance other than cold glass and a few pure rubber connectors, which were made as short as possible by abutting the ends of the adjacent tube sections. Inasmuch as the liquid lava contains nearly 10 per

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[1] The chemical and physical tests offered by Brun in support of his conclusions (5) and (6), page 278, are also somewhat inconclusive. For example, he tests for chlorine with a silver nitrate solution in an atmosphere containing S, SO₂, and SO₃, and notes that it immediately becomes clouded, but mentions no test to ascertain whether it was the chloride or the sulphite which was thus precipitated. Similarly, he nowhere offers a chemical analysis of these particular gases which he collected in tubes at Kilauea, but contents himself with presenting two analyses of other gases pumped from lava fragments reheated in vacuo some months afterwards.

PLATE 3.

POSITION OF THE DOME (MAY 28, 1912).

Enlarged from a small photograph to illustrate the position of the dome (D) from which gases were collected on May 28, 1912, with reference to the lava lake (on the right).

PLATE 4.

VIEW WITHIN THE ACTIVE PIT, HALEMAUMAU (MAY 28, 1912).

Showing the dome from which gases were collected, the line of tubing on the lava floor, together with the collecting tubes and pump

cent of FeO, the momentary contact of the gases with the oxidized surface of the iron was not accounted a serious disturbing factor.

The other end of the tube system was connected to a piston pump about 4 inches in diameter, with a displacement of about $2\frac{1}{2}$ liters per stroke to insure a rapid passage of the gases through the tube system.

The gases entered the pipe line at a temperature of about 1,000°. Their path was through the 12 inches of iron pipe, about 20 feet of glass tubing (pure rubber joints at 4-foot intervals), then through 20 collecting tubes and out through the pump at the back.   The pumping was kept up for 15 minutes in order to make sure that the air originally contained in the pipe line and connecting tubes was displaced by the gases from the volcano, after which the pump and pipe line were sealed off with pinchcocks and the crates raised to the rim. In this pipe line water began condensing with the first stroke of the pump, and at the end of 15 minutes about 300 cubic centimeters had accumulated in the collecting tubes.   It was clouded with free sulphur, partly from the original emanation and partly from the action of the iron tube on the sulphur dioxide contained in the emanation.

In arranging this experiment Brun's conclusions were known to us, and accordingly we had provided ourselves with apparatus for collecting fixed gases only.   We were wholly unprepared for any which might condense in passing through the collecting tubes.   What we obtained, therefore, was a quantity of the fixed gases, which may be assumed to be approximately in the proper quantitative relation one to another, and water, the latter in considerable excess from the fact that it was not pumped through the tubes with the fixed gases, but condensed and remained behind, chiefly in the first three or four tubes.   There is, therefore, no way to estimate from the results of this experiment the proportion of water to the total quantity of volatile matter discharged from the lava.   Perhaps this should be regarded as a fortunate mischance notwithstanding, for we were thereby enabled to gather a quantity of water sufficient to establish its existence among the volatile ingredients exhaled by the volcano beyond the criticism of the most skeptical.   Furthermore, the condensing water by its accumulation in the first tubes served as a kind of wash bottle for the collection of any soluble material contained in the gaseous emanation.

The next day we began preparations to meet the emergency thus thrust on us by building in the laboratory of the Hawaiian Volcano Research Association[1] an extemporized mercury pump of the dis-

placement type and vacuum tubes especially arranged to meet the conditions which we had found. These tubes were of the same capacity as the individual tubes in the previous experiment (one-half liter), but were provided with a long stem, on the remote end of which was blown a thin glass bulb. The plan was to attach these tubes to a pole of convenient length and to thrust the end carrying the thin bulb into the dome, where the heat might be expected to explode the thin glass immediately, permitting the tube to fill with the gases, and as quickly to seal it again by melting down the broken end. The tubes were dried in contact with phosphorus anhydride and the degree of exhaustion checked by electrical discharge tests from a small static machine. When a number of these tubes had been prepared and everything was ready for a second attempt, the top of the lava dome had fallen in and the liquid lava in the basin had gone down to such an extent that it offered no further opportunity to collect gases under conditions which should assure original gas without contamination from the air or otherwise. In fact no other opportunity offered until December 4.[1]

THE SECOND ATTEMPT TO COLLECT GASES.

On December 4, with the lava surface 360 feet below the rim, and therefore even less conveniently accessible than on the previous occasion, a similar dome formed directly on the border of the lava lake, and the second attempt was made to collect a quantity of gas—this time in the vacuum tubes. In order that there might be no possible doubt about the excess gas pressure within the lava dome, the descent into the crater was made at night, when the pale blue flame of the escaping gases could be plainly seen emerging from the crack in the dome. The manner of collecting the gases was exactly that which was planned and described above, and six tubes were filled with gas under these conditions.

On descending into the crater to collect gases from the December dome, it was found that in addition to a long slit or crack across the top, from which the gases were discharging constantly, there was a second opening near the base which was not noticed before the descent, but which gave access to air at the base of the dome and thus behaved like an air blast in a furnace. The gases were therefore partly burned within the dome instead of outside, and the tubes, which were filled at the upper opening, were accordingly found to contain chiefly burned gases—that is, the free hydrogen had become water, the free sulphur had burned to SO_2, the CO appeared as CO_2, etc.

Although the identity and something of the relation of the gases discharged from the basin of Halemaumau can be established from a

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[1] In the meantime one of the authors (Day) was obliged to return to Washington, leaving the other (Shepherd) to finish the task alone.

study of the material collected in May, the determination of the exact proportion of water to the other gases present must await another favorable opportunity. It may perhaps be added that a complete equipment for another attempt lies ready at the laboratory of the Volcano Research Association on the crater rim, but the lava lake disappeared completely from view soon after the December descent was made and has not again reappeared.

Although the continuation of the field studies must await the gracious pleasure of the most fickle of goddesses, it need not delay the prosecution of the laboratory study of the relations between the gases already found or the preliminary discussion of the results thus far attained. Moreover, in the discussion which follows, evidence will be offered that the composition of the gases varies within considerable limits, so that the precise proportions of the gases which go to make up the exhalation at any particular moment may prove to be of less importance than was at first believed.

CHEMICAL STUDY OF THE MATERIAL COLLECTED.

From a physicochemical viewpoint, the study of volcanic activity centers first on the nature of the participating ingredients, then on the condition of equilibrium or the progress of the reactions taking place between them, as the case may be. At the time of our two visits all the three states of matter—gaseous, liquid, and solid—were found represented. Gases were emitted constantly in great volume, and displayed nearly all the great variety of cloud forms which have been so frequently described in volcano literature except the violently explosive type, which has been rarely or never seen at Kilauea since the advent of the white man (1820). There was a liquid lava basin of oval shape some 600 by 300 feet, inclosed by a lava dike or rampart built up from the surrounding floor of the basin by the tumultuous spattering and splashing of the lava lake (pl. 5). Both floor and rampart are frequently overflowed when the lake is high, and again great masses of it fall into the lake and are redissolved when it is low. The floor of the pit at the time of our first descent in May, 1912, had been completely overflowed but three days before and was reasonably level. The fresh lava had solidified to a depth of some 10 inches and was abundantly solid to walk on, but was still uncomfortably hot and the cracks were still glowing.

Surrounding this floor are the walls of the pit, some 200 feet high at the time of our first descent and made up of the exposed edges of successive earlier overflows (pl. 6), which individually rarely exceeded 2 or 3 feet in thickness. The (Halemaumau) pit as a whole was about 1,500 feet in diameter, roughly circular in plan, and with nearly perpendicular walls except for the talus pile at the base, which extended about half way up the wall. All these dimensions vary

somewhat from day to day and considerably from year to year with the state of activity in the basin. The appearance of the lake and its surroundings is perhaps best shown by a photograph (pl. 7) made from a slight elevation above the floor of the active basin on May 23, 1912.

ANALYSES OF THE LAVA.

The composition of the liquid lava in the lake and of the solid floor of the Kilauea crater near the Halemaumau pit may be seen from analysis 1a and 1b, which follow:

TABLE 1.

Analysis 1a.

Lava from floor of Kilauea: Forty to 50 per cent glass; 5 to 10 per cent olivine; 5 to 10 per cent feldspar phenocryst; rest very fine crystals. (Merwin.)

	Per cent.
SiO_2	50. 07
Al_2O_3	13. 32
Fe_2O_3	1. 92
FeO	9. 28
MgO	8. 01
CaO	10. 64
Na_2O	2. 16
K_2O	0. 45
H_2O+	0. 49
H_2O-	0. 22
CO_2	None.
TiO_2	2. 70
ZrO_2	None.
P_2O_5	0. 26
SO_3	None.
Cl	0. 08
F	None.
S	0. 11
Cr_2O_3	0. 05
MnO	0. 16
NiO	0. 04
BaO	None.
SrO	Trace.
Li_2O	None.
V_2O_5	None.
Rare earths	None.
MoO_3	Trace.
Ignition loss	0. 36
	99. 96

After correction for Cl, etc____ 99. 89

Analysis 1b.

Lava dipped from Halemaumau July 23, 1911. Glass, with 1 per cent feldspar and trace of crystals of either magnetite or pyroxene. Index 1.605, lining of bubbles slightly higher. (Merwin.)

	Per cent.
SiO_2	49. 74
Al_2O_3	12. 36
Fe_2O_3	1. 64
FeO	10. 08
MgO	8. 83
CaO	10. 88
Na_2O	2. 45
K_2O	0. 55
H_2O+	0. 17
H_2O-	0. 05
CO_2	None.
TiO_2	2. 49
ZrO_2	Trace.
P_2O_5	0. 41
SO_3	Trace.
Cl	0. 10
F	None.
S	0. 04
Cr_2O_3	0. 04
MnO	0. 14
NiO	0. 05
BaO	Trace.
SrO	0. 07
Li_2O	None.
V_2O_5	0. 02
Rare earths	Trace.
MoO_3	0. 01
	100. 12

After correction for Cl, etc____ 100. 08

PLATE 5.

VIEW OF THE LAVA LAKE AT CLOSE RANGE (MAY 28, 1912).

Taken within the crater immediately after plate 4. The incfosing dike due to the spattering of the lava is well shown. A portion of the dike a little to the left of the center of the picture fell into the lake a few moments after the exposure.

PLATE 6.

VIEW OF THE LAVA LAKE AT CLOSE RANGE (JUNE 29, 1912).

Showing also the inclosing wall of the pit. Note the absence of smoke above the active lava.

The sample 1*b* was dipped from the middle of the lava lake on July 23, 1911, by Mr. Frank A. Perret and one of the authors (Shepherd),[1] with the help of a cable and trolley, stretched directly across the center of the pit, and appropriate tackle. The sample 1*a* was taken from one of the recent overflows on the main floor of the Kilauea crater and may perhaps be 15 or 20 years old. The substantial identity of the analyses with each other and with other recent analyses of the lavas of Hawaii[2] shows that no material change in its composition has taken place in recent years. The most noticeable feature of the new analyses is perhaps the presence of a small amount of molybdenum, which appears not to have been detected hitherto. The analyses were most carefully made by Mr. John B. Ferguson, of this laboratory, to whom we take this opportunity to express our thanks.

THE GASES AND DIFFERENT WAYS OF STUDYING THEM.

The problem of collecting volcanic gases which are satisfactory from the chemical viewpoint is a much more difficult matter, as has been already intimated. Hot gases of more or less complicated composition discharged from an active volcanic vent into the air undergo immediate and violent chemical and temperature changes, the consequences of which, with our present limited knowledge of gas relations at these temperatures, can be only partly inferred. It is therefore a matter of the first importance to collect the gases directly from the liquid lava or the explosive vents before contact with the air has given opportunity for these alterations to occur. It may very well be that the physical difficulties attending the collection of volcanic exhalations, particularly from volcanoes of the explosive type, will often make it impossible to obtain unaltered magmatic gases for laboratory study, in which case burned gases, or even very dilute mixtures of these with air, may prove to be the only products available for study. In this event the student must perforce bow to the necessities of the case.

Something of the same cautious attitude requires to be maintained toward the study of the flame spectra of burning volcanic gases. The pocket spectroscope is primarily an instrument of preliminary reconnaissance in the field and is sometimes of value, but the pale-blue flames of sulphur and hydrogen are extremely difficult to analyze with the pocket spectroscope, and can not be distinguished at all against a bright background of solid or liquid lava. For this reason

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[1] This expedition was sent out by the Massachusetts Institute of Technology (Prof. T. A. Jaggar) in the summer of 1911 for the purpose of securing a trustworthy measurement of the temperature in the lava lake. The record of the expedition has not been published.

[2] R. A. Daly: Magmatic differentiation in Hawaii. Journal of Geology, vol. 19, 1911, p. 305.

W. T. Brigham: Loc. cit., p. 33.

a more elaborate spectroscopic equipment would not help the matter. Moreover, the gases are much altered or are in process of active alteration before any opportunity for identification is offered, and no estimate of the relative quantity of the various participating gases is possible by this means. Inferences from the chemical study of gases which have been burned by contact with the air while still hot and inferences from the spectroscopic study of the gases while burning therefore suffer alike from limitations of principle and should be resorted to only when the difficulty of collecting unaltered gas is insuperable.

These reasons may serve to show why this somewhat elaborate effort was made to collect unaltered gases for laboratory study and why we are inclined to give greater weight to the results obtained from the study of such gases than to many of the earlier studies[1] of volcanic emanations, in which the gases had become altered through contact with the air or otherwise.

The domes from which these gases were collected were built up by the lava itself on the floor of the crater (Halemaumau) and were both chemically and physically ideal gas collectors, being lined with fresh splashes of liquid lava of the same temperature and chemical composition as that from which the gas had just emerged. They formed at the level of the lava lake and, as could be plainly seen after the collapse of the domes, were directly connected with the lake by channels of liquid lava just below the surface crust. The collapse of the entire channel leading to the May dome is shown in plate 8, figure 1, in which an arrow (†) has been placed to indicate the position where the dome stood. The May dome was under constant observation for several days and a considerable portion of the night immediately previous to the collection, during which time there was no cessation of the lava fountain spouting within the dome nor of the flames of the burning gases as they escaped through its cracks. Furthermore, as the larger bubbles rose and burst from the liquid lava within the dome, the jar could be felt on the floor where the collectors stood and the splash could be plainly seen through the cracks.

ANALYSES OF THE GASES COLLECTED IN MAY, 1912.

The following analyses were made of the fixed gases collected in glass tubes on May 28, 1912, in the manner above described. The statement is given in parts by volume. The tubes were numbered from 1 to 20 in the order in which the gases entered from the volcano. All the tubes contained condensed water (the first—pl. 8, fig. 2, containing nearly 100 cu. cm.), of which analyses will be found on page 292.

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[1] E. g., Wm. Libbey: Amer. Journ. Sci. (3), vol. 47, 1894, p. 371.

PLATE 7.
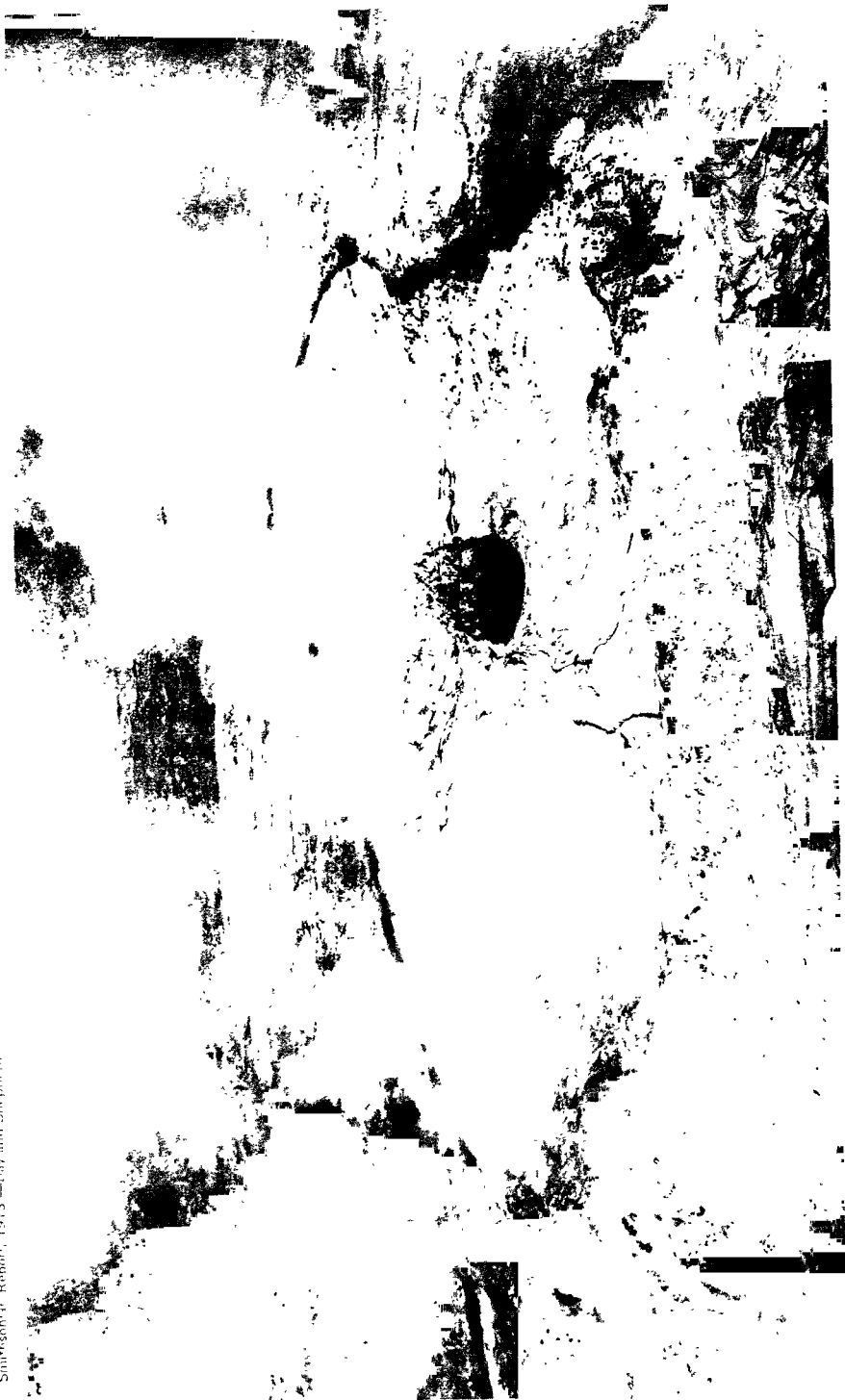
VIEW OF THE LAKE AS A WHOLE IN A PERIOD OF MODERATE ACTIVITY (MAY 23, 1912).

Note the agitation both left and right and the formation of ropy lava in the foreground. The bursting bubble is about 30 feet in diameter.

PLATE 8.

FIG. 1.—VIEW OF LAKE AND THE SHATTERED FLOOR FIVE DAYS AFTER GASES WERE COLLECTED (JUNE 2, 1912).

Showing (1) place where the dome had stood. Beneath the crack where the cloud issues extends an arm of the lake.

FIG. 2.—VIEW OF TUBE NO. 1 IN THE LABORA-TORY READY FOR ANALYSIS.

Showing condensed volcanic water. The quantity is about 100 cubic centimeters.

LAKE WHERE GASES WERE COLLECTED AND TUBE CONTAINING CONDENSED VOLCANIC WATERS.

TABLE 2.—*The gases from Halemaumau (Kilauea), May, 1912.*

[Percentages by volume.]

	Tube 1.	Tube 2.	Tube 8.	Tube 10.	Tube 17.
CO_2	23.8	58.0	62.3	59.2	73.9
CO	5.6	3.9	3.5	4.6	4.0
H_2	7.2	6.7	7.5	7.0	10.2
N_2	63.3	29.8	13.8	29.2	11.8
SO_2	.0	1.5	12.8	.0	.0
Rare gases	.0	.0	.0	.0	.0
Hydrocarbons	.0	.0	.0	.0	.0

THE INFLUENCE OF THE IRON COLLECTING TUBE.

In the 15 minutes during which pumping was continued the short length of iron pipe which extended into the dome was partly destroyed by the joint action of the sulphur and SO_2. Owing to the high temperature and the splashing of the molten lava, neither glass nor porcelain would have withstood the ordeal, and a tube of silica glass was, unfortunately, not available; so that iron appeared to be the best material at hand through which to reach the interior of the dome and to insure the capture of the gases at the temperature of emergence from the lava (about 1,000°) before any opportunity for cooling or contact with air had been given.

The effect of this small section of iron pipe on the relations between the gases collected in the tube is not as great as might at first appear. The action of SO_2 on iron at this high temperature is quite vigorous, the iron going over to ferrous oxide and setting free the sulphur. But both these ingredients are present in the lava already, as may be seen from the analyses (Table 1), so that no new component is added, nor is any new reaction precipitated through the introduction of the iron. It might be assumed further that the free hydrogen present would be partly oxidized to water in reducing the ferrous oxide formed from the SO_2 and iron (this is one of the reactions when these components are brought together at this temperature in the laboratory), but if this reaction has had a share in the disposition of our bit of exposed iron we must admit its presence in overwhelming magnitude over the entire inner surface of the dome, which is everywhere lined with liquid lava containing nearly 10 per cent of ferrous oxide. The assumption of this reaction would therefore have the immediate effect of establishing the presence of water in quantity among the volcano gases and at the same time relegate the influence of the iron tube to a position of entire insignificance.

There is still further evidence, if more is needed. that the local reactions set up by the iron are of subordinate importance only in their effect on the proportions of the gases collected, and of no effect whatsoever on their identity and chemical relation. Supposing these

reactions to have occurred as described, it is then a matter of straight-forward computation to show that if the known weight of iron which was dissolved away by the gases, both those which entered the pipe and those which merely played on its outside wall,[1] had reacted in this manner; and supposing further that all the products of the reaction, both outside and inside, entered the collecting tubes (which is obviously impossible), it would have involved pumping through the system some 225 liters of pure hydrogen as an equivalent for the iron consumed, and this still falls short of the quantity required to account for all the water collected by more than 40 per cent. More-over, if the attempt is to be made to account for all the water col-lected in our tubes through reactions requiring free hydrogen, it is altogether inconceivable that any such quantity of uncombined hydrogen is available in the emanation from the volcano. For if we were to assume that as much as 1,000 liters of volcanic gas (which is a very liberal estimate) passed into the collecting train in the 15 minutes during which the pumping was continued, such a quantity of free hydrogen (375 liters) would be equivalent to 40 per cent of the total composition, a quantity sufficient to form an explosive mix-ture on contact with air of such extreme violence as to change the entire character of the volcanic activity at Halemaumau. It is a fact of general observation that the bubbles of gas which come up through the liquid lava, even when they reach the enormous size of 30 feet in diameter, give no explosion whatsoever.

We may therefore fairly conclude, both from the character of the reactions in which the iron might have a part and from the quantity of water collected, that the presence of the iron tube has no consider-able significance in relation either to the character or to the amount of volatile material collected.

THE REACTION BETWEEN H_2 AND SO_2 OR CO_2.

To this reaction assumed to be going on between H_2 and FeO may be added another and much more important one in which the iron has no part. The free hydrogen set free by the volcano reacts with sulphur dioxide at 1,000° to give water and free sulphur directly. It will also be recalled that carbon dioxide and hydrogen undergo similar reaction at this temperature. This is the familiar water-gas reaction

$$H_2 + CO_2 \leftrightarrows CO + H_2O$$
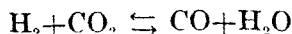
which has been thoroughly studied by Haber[2] and others throughout the entire range of temperatures found to prevail at this volcano, and may be accepted without limitation as an important factor in the

[1] The scale on the iron pipe after exposure was found to contain over 85 per cent of ferrous oxide and about 8 per cent of sulphur.

[2] See, for example, F. Haber: "Thermodynamik technischer Gasreactionen," p. 158. München, 1905.

activity which we are studying. It follows directly from this that the chemical analyses of volcano gases offered by Brun in support of his conclusion that the exhalations from Kilauea and other volcanoes are anhydrous, also carry on their face the clear proof that his conclusion is untenable. Neither CO_2 nor SO_2 can be associated with free hydrogen at temperatures in the vicinity of 1,000° without the formation of water. The two analyses offered by Brun of the gases given off on reheating the Kilauea lava show them to be chiefly made up of precisely these ingredients (loc. cit., p. 115) :

Brun's analyses of gases obtained from Kilauea lava when heated in vacuo.

1.		2.	
HCl	Traces.	Cl (libre)	5. 58
SO_2	1. 7	HCl	1. 71
CO_2	50. 8	SO_2	4. 72
CO	17. 3	CO_2	69. 09
H_2	28. 5	CO	11. 60
N_2	1. 2	CH_4	0. 85
		H_2	6. 10
		N_2	0. 3

It is, furthermore, noticeable that the analyses here offered by Brun as representative of the gases emanating from Halemaumau do not in any way agree with the composition of the gas which we obtained from liquid lava. He finds, for example, in one analysis more than 7 per cent of chlorine in one form or another where we find 0.02 per cent or less. He obtained about 5 per cent of SO_2, whereas SO_2 during our visit was perhaps the most notable gas evolved from this crater.

THE RELATIVE QUANTITIES OF THE CONSTITUENT GASES.

Leaving now the question of the identity of the gases discharged by the lava at Halemaumau, we should perhaps turn for a moment to the consideration of their relative quantity, which, as already intimated, is not so well established by our samples because of the unexpected presence and condensation of the water in the collecting tubes.

In addition to the presence of the iron tube, and its possible effect on the total quantity of water and of free sulphur collected in our tubes, which has been discussed above, our analyses of the gases (p. 289) are subject to a second limitation which is at once obvious. When the pumping had been completed, the collecting tubes each contained a quantity of the condensed water, in which the fixed gases are individually soluble in varying degree both during and after cooling. There is also some reaction between the gases and water. The long period which elapsed between the date of collecting the gases and their analysis in Washington after the close of the field season—nearly a year—gave opportunity for these readjustments to proceed practically to completion. The SO_2, for example, has gone

over in part or altogether to SO_3 and gone into solution, and only two of the five tubes analyzed now show SO_2 as such. Moreover, the resulting acid solution may have reacted to a limited extent on the glass tube, and accordingly be responsible for all or a part of the alkalies, lime, and alumina shown in analyses of the water (table 3).

PRELIMINARY ANALYSIS OF ONE TUBE OF GAS IN HONOLULU.

For this reason some importance attaches to a preliminary and very hasty analysis of the contents of one of the tubes (No. 3) made but four days after the collection, for which the College of Hawaii most courteously extended the facilities of its chemical laboratory at Honolulu. This preliminary analysis was undertaken solely as a precaution against the consequences of a possible total loss of the material collected through accidents of transportation.

Owing to the limited facilities, it was not possible to make a complete analysis; but in tube No. 3 shaking with water reduced the total volume of gas by 51.6 per cent, which may fairly be assumed to represent the SO_2 in this particular tube. As there was a quantity of the condensed volcano water in the tube already, this merely reveals the quantity of SO_2 in excess of the quantity already taken up by this water. The carbon dioxide of this tube amounted to 39.8 per cent, but was probably contaminated with some SO_2. The CO amounted to 5.5 per cent. The hydrogen and nitrogen could not be determined, but there was not enough hydrogen in the residual gas to form an explosive mixture when mixed 1:1 with air. The water in this tube gave a very slight turbidity with acid silver nitrate and a slight precipitate of SO_3. This latter represents the amount formed in the tube in the time which elapsed between the collection and analysis (four days). This tube gave no test for titanium.

Hydrocarbons could not be detected in any of the tubes.

THE MATERIAL PRESENT IN THE WATER.

The water which was collected in the first tubes of the series may fairly be assumed to contain practically all of the halogens. The analysis of this water is given in Table 3.

TABLE 3.—Analyses of material contained in the water collected in the tubes.

	Tube 1.	Tube 2.	Remarks.
	Grams.	*Grams.*	
Na₂O	0.0214	0.031	
K₂O	.0102	.011	The major portion of these
CaO	.0120	.14	may have come from the
Fe₂O₃ }	} .080	.010	glass or from Pele's hair.
Al₂O₃ }			
Cl	.220	.206	
F	.565	.492	
NH₃	.0018	0	
TiO₂	.005 (?)	.0	
Total S as SO₃	.480	.508	

It is not improbable that most of the alkalies, lime, and alumina have resulted from the action of the acid liquid on the glass tubing, but it is of the greatest importance to establish the fact that the entire quantity of gas pumped through the "wash bottle" yielded no more than 0.4 gram of chlorine. If this be calculated in the form of gas, it will correspond at most to 0.02 per cent, assuming that approximately 1,000 liters of gas were drawn into the tubes. Fluorine seems to be present in about twice this quantity, but in no sense can these halogens be regarded as forming more than a very minor part of the crater exhalation.

RARE GASES.

In the progress of the analyses, after all the active gases had been removed from the several tubes analyzed, there remained an inactive residue which, of course, consisted mainly of nitrogen, but which might be supposed to contain traces of argon, helium, or other of the rare inert gases, should any such chance to have been present in the volcano emanation. For the determination or detection of these several of the residues were brought together in a spark tube and exposed for several hours, in the presence of oxygen, to an alternating-current spark discharge of considerable intensity. When the volume of residual gas could no longer be diminished by this means, there remained a final residue of 75 cubic centimeters of gas, which was forwarded to Prof. R. W. Wood, of Johns Hopkins, who very kindly offered[1] to make a spectroscopic examination of it for traces of the rare gases. The search yielded a decisive negative result. No lines characteristic of any of the rare gases could be found with the spectroscope, nor did exposure to charcoal at the temperature of liquid air leave any residue whatever. The gas examined was, therefore, all nitrogen. Subsequently the residues (15 cubic centimeters) from another group of the tubes were treated in the same way and forwarded to Prof. Wood, who was again able to detect nothing but pure nitrogen. It appears to be definitely established, therefore, that the gases collected from Halemaumau in May contain nitrogen but no argon. This affords a most desirable confirmation of our belief that the volcano gases were successfully collected before they had come in contact with atmospheric air at all, and were therefore entirely uncontaminated either by reaction or admixture with it. It also offers support to the view that the volcanic nitrogen is not of atmospheric origin—to which further allusion will be made in the concluding paragraphs.

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[1] We desire to take this opportunity to thank Prof. Wood for courteously offering to examine these gas residues. The Geophysical Laboratory at Washington possesses neither the equipment nor the special experience necessary to undertake a spectroscopic study of this critical character.

THE GASES COLLECTED IN DECEMBER, 1912.

From the gases which were collected in vacuum tubes on December 4, 1912, much less information is obtainable than from the May collection, in spite of the more elaborate preparations made for the second attempt. This was wholly due to the fact already mentioned, that the dome from which the December gases were collected proved on near approach to be an imperfect one, which permitted the entrance of air and a partial combustion of the gases within the dome. Six individual vacuum tubes (two of one-half liter capacity and four of 250 cubic centimeters) were automatically filled and sealed off within this dome and were brought to Washington in safety, but were found on opening to contain mixtures of volcano gases and air, such as might be expected from exposure to the temperature at which they were collected (about 1,000°). There is, of course, no more reason for expecting the chemical reaction between the gases and air to have proceeded to an equilibrium than in the case of the reactions between the volcanic gases alone, whence the analyses of the gases contained in these tubes may be expected to show very variable proportions.

In stating the analyses the free oxygen found has been subtracted, together with a corresponding portion of the nitrogen appropriate to the normal composition of air. Probably more of the nitrogen should have been subtracted as an equivalent for the oxygen taken up in the combustion of the sulphur products and carbon monoxide, but the amount would be difficult to fix in view of the reactions between the volcano gases themselves and it has not been attempted. The analyses at best add but little to the knowledge already obtained.

TABLE 4.—*Analyses of gases collected in December, 1912.*

[Percentages by weight.]

	Tube 2.	Tube 3.	Tube 5.
CO_2	49.6	33.7	45.4
N_2	24.1	32.1	21.3
H_2O	26.2	26.6	29.7
SO_2	.0	7.6	3.5
Cl	Trace.	.0	.0
F	.0	.0	.0

If we make the only available assumption, namely, that the oxygen which is now present as water, if it came from the air, must have left behind a corresponding amount of nitrogen. then the amount of nitrogen found in these three vacuum tubes is in every case two or three times too small. For example, in tube No. 2, if all the oxygen now contained in the water came from admixed air, there should have been at least 240 cubic centimeters of nitrogen in this tube

instead of 74 cubic centimeters, as actually found. There is but one conclusion, namely, that only the minor portion of the water found in the tubes was formed through reaction with atmospheric oxygen. Here again, therefore, we have corroborative evidence of water emanating directly from the liquid lava.

None of these vacuum tubes gave a test for ammonia, which is not surprising, since the water collected in May showed only a trifling amount. With the possible exception of 5 milligrams of insoluble residue found in tube No. 1 of the May collection, no titanium was present. The other tubes of the series yielded none on test.

THE HOT EMANATIONS FROM CRACKS ABOUT THE HALEMAUMAU CRATER.

It was thought desirable to collect and analyze the gases from a number of the hot cracks which occur outside the rim of the Halemaumau pit (see pl. 1) for comparison with the gases exhaled from the liquid lava. One of the cracks forms an almost complete ring around the pit at a distance of about 150 meters from the rim. While this crack appears practically continuous, there are a number of points where the gaseous exhalations are much more voluminous than at others. The small steam cloud in plate 1 comes from this crack. The temperature of the gases obtained at points on this circular crack and some 10 feet below the surface were quite uniformly between 190° and 200°.

At the most noticeable of these "hot spots," locally known as the "Devil's Kitchen" or "Postcard Crack," and situated northeast of the Halemaumau pit, the surface lava flows are much decomposed, and consist of a coarse, somewhat sandy mixture of calcium sulphate, alum, ferric sulphate, and much free sulphur. In the gaseous exhalation the amount of SO_3 occurring as such is relatively high, while CO_2, SO_2, and free sulphur are also present in large quantities. A vacuum tube filled at this point yielded in weight per cents:

[Per cent by weight.]

CO_2	3. 64
O_2	19. 54
N_2	66. 71
H_2O	9. 74
SO_3[1]	. 37

Other tubes which were filled by pumping at this crack were found to contain fixed gases as follows:

[Per cent by volume.]

CO_2	5. 8
O_2	18. 2
N_2	76. 0

[1] The total sulphur computed as SO_3.

while the water (about 20 cubic centimeters) yielded:

	Gram.
Cl	0.0513
F	.0079
SO	.328
NH	.0

Another spot of great gaseous activity occurs in this circular crack near the terminus of the automobile road and southeast of the center of the active pit. The vacuum tube taken at this point yielded:

[Per cent by weight.]

CO_2	8.12
O_2	14.58
N_2	51.20
H_2O	25.49
SO_3	.59
Cl	undet.

The water contained in the tube which was filled by 15 minutes' pumping at this point (amounting to about 15 cubic centimeters) yielded the following:

	Gram.
Cl	0.0298
F	.0
SO_3	.656

Fifty meters to the northeast of this point, along the same crack, the gas obtained was merely moist air, with a trace of SO_2 and uncertain traces of Cl.

About 100 meters south of the terminus of the automobile road is a moist region, where the decomposed lava rock was found to be more or less saturated with sulphuric acid, the decomposition products being black rather than the bright sulphur yellow prevailing at the points above described. A vacuum tube taken in this region, which is again on the circular crack surrounding the pit and nearly due south of it, yielded:

[Per cent by weight.]

CO_2	9.64
O_2	18.18
N_2	63.85
H_2O	7.81
SO_3	.51
Cl	.0

The water condensed in a tube filled by pumping at this point yielded about 3 milligrams of chlorine, but no flourine.

With regard to the chemical products along this circular crack about the crater basin of Halemaumau, we can sum up by saying that water, although no doubt partly of meteoric origin, was always present at the time of our visit, and the gases were prevailingly high in

carbon dioxide, sulphur dioxide, and sulphur trioxide. Only at the automobile road terminus was chlorine found to be present in an amount sufficient to show appreciably in a field test.

Cracks farther removed from the Halemaumau pit show in some cases small amounts of SO_2, but more frequently exhale merely steam. Thus in caves where stalactites are forming at a temperature of about 40°,[1] the gas present was in all cases examined merely air and steam and contained no more CO_2 than is normally contained in the air. The formation of the stalactites in this cave is accompanied by the formation of gelatinous silica in the presence of some kind of green algæ. As might be expected, neither carbon monoxide nor hydrogen was detected in the gases taken from these cracks.

SUBLIMATION AND DECOMPOSITION PRODUCTS.

Numerous samples of decomposed lava were taken from various points around the crater where the alteration of the surface lava is conspicuous. While the examination of these is not complete, the preliminary results can be summed up by saying that the samples consist primarily of the products to be expected from a sulphuric acid decomposition of the usual basic lava. In most of the places where these samples were gathered the surface is constantly bathed by the volcanic cloud carrying SO_2, SO_3, and free sulphur, together with steam; which ingredient predominates is of no particular interest, so far as the general problem of surface alteration is concerned. In addition to the gaseous products, the breaking down of the lava results in ferric sulphate, which is formed more or less rapidly from the oxide in presence of steam. Alum occurs at favorable places over most of the main floor of the Kilauea Crater, but the amount is relatively small. Gypsum is perhaps the most common decomposition product which is left, and this occurs all over the crater. Projecting lava points on the under side of a lava block will often be found tipped with small crystals of gypsum.

Since the gases collected point uniformly to the conclusion that the amount of chlorine given off by the crater at the time of our studies was relatively insignificant, it seemed worth while to look for it, as Brun had done, in the older lava which had been exposed to the fumes of the crater for several years. A specimen of lava was accordingly taken on the lee side of the crater rim, where it had been fumed with the gases carried over it by the trade winds for 20 years or more. This lava in a 2-gram sample yielded no test for chlorine. This result is not as satisfactory as it might otherwise be from the fact that the major portion of the exhalation of the volcano is SO_2,

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[1] W. T. Brigham : "The volcanoes of Kilauea and Mauna Loa on the Island of Hawaii." p. 29. Honolulu, 1909.

which, when combined with water, readily changes to sulphuric acid and would tend to drive the chlorine out of any combinations which it might form. It constitutes, nevertheless, a plain indication that the amount of chlorine actually evolved is insignificant.

DISCUSSION OF RESULTS.

GENERAL CONCLUSIONS.

In so far, then, as this reconnaissance yields final results, it shows that the gases evolved from the hot lava at the Halemaumau Crater are N_2, H_2O, CO_2, CO, SO_2, free H, and free S, with Cl, F, and perhaps NH_3, in comparatively insignificant quantity. No argon or other rare gases and no hydrocarbons were found.

THE EFFECT OF THE REACTIONS BETWEEN THE GASES.

The first plain conclusion which follows from the discovery of this particular group of gases associated together at a temperature of 1,000° or more is that they can not possibly be in equilibrium there, and that chemical action between them is still going on. Whatever may have been the previous opportunities for chemical readjustment among the gases as they rose in solution with the magma and were gradually set free with the diminishing pressure, they are still in process of active reaction when discharged into the air. Free sulphur, for example, could not have remained in permanently stable association with CO_2; neither could free hydrogen be found in stable association with CO_2 and SO_2 at 1,000°.

THE EFFECT OF THE EXPANSION OF THE GASES.

Moreover, as the pressure continued to diminish during the progress of the upward movement, the quantity of gas released from solution, and therefore free to enter into new relations, must have been constantly and rapidly increasing up to the moment of discharge into the air.

Two consequences follow from the continuation of this operation, which are thermally opposite in sense. First is the rapid expansion of the gases with the release of pressure, which is a cooling phenomenon, and which, if the expansion takes place suddenly from a high pressure into the air, might finally be extremely rapid.

AN EXPLANATION OF THE FORMATION OF AA LAVA.

Parenthetically, it may be noted in passing that such rapid expansion and consequent cooling when occurring suddenly at the surface may very well be the sufficient cause of the Aa lava formations. Great blocks appear to have cooled in this way so rapidly that no opportunity was given for the suddenly projected and rapidly expanding lava outbursts to " heal " and resume liquid flow. The pro-

jected masses are cooled almost instantly throughout their mass and remain discrete blocks of the roughest and most ragged outline (pl. 9), which are pushed forward thereafter in a manner which has been likened to a "moving stone wall," beneath which the advancing liquid can rarely be seen. This hypothesis of the manner of formation of Aa lava has encountered no limitation from a field examination of Aa flows at the point of outbreak, and enjoys still further confidence from the fact that this is almost the only conceivable method of bringing about a nearly instant cooling throughout the mass of a very large block of lava. (Aa blocks are sometimes reported to reach the size of a small house.) Any manner of cooling from the outside inward in such masses must have resulted in much mechanical deformation during the forward movement after the surface had "set," causing rupture and outbursts of imprisoned liquid, none of which were found in the field.[1]

The rate of cooling of gases expanding adiabatically has been especially emphasized by Daly,[2] who has contended that when the liquid lava finds exit through a long and rather narrow pipe. like the vent at Halemaumau, the pressure must diminish rapidly as the lava rises, and the temperature must fall rapidly in accordance with the law of adiabatic expansion. In order to maintain such an exposed surface basin in the liquid state, it is then necessary to postulate a very high temperature for the lava far below the surface,[3] but this has serious difficulties because of the chemical complications which would follow from it.

CHEMICAL REACTION BETWEEN THE GASES.

The second consequence of the gradual release of gases is the interreaction between the gases thus set free in constantly increasing quantity as the surface is approached. These reactions are accompanied by evolution of heat, which obviously operates to raise the temperature of the surrounding lava so long as the reacting gases remain in contact with it. The heat generated by these gas reactions, in the region near the surface where the amount of gas is large, may well be much more than sufficient to counteract the cooling effect of the expansion within the rising lava column, which may thus become hotter and not cooler as it approaches the surface.

Precise figures can hardly be given for the difference in magnitude between the two forces which have been assumed to oppose each other

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[1] For other explanations of the formation of the Aa lava see Green, loc. cit., p. 171; Hitchcock: "Hawaii and its volcanoes," p. 282. Dana: "Characteristics of volcanoes," p. 241.

[2] R. A. Daly: "The nature of volcanic action." Proc. Amer. Acad. Sci., vol. 47, 1911. p. 84.

[3] Daly has calculated a temperature gradient of 2,000° per 37 meters of depth for the rate of cooling of the gas alone, but the calculation takes no account of the relatively enormous mass of adjacent lava which must be cooled by the gas.

here, the adiabatic cooling on the one hand and the heat of reaction between the gases on the other, for we do not yet know what all the reactions are in such a complicated chemical system, nor do we possess any knowledge of the height of the lava column through which the gases are free to react. In fact, if the tube which feeds the volcano from below be supposed to contain both ascending and descending columns of liquid lava of widely variable temperature (Daly) in which the circulation is primarily controlled by the (relatively very large) differences of specific gravity, then it is indeed questionable whether the common equations for adiabatic expansion find application here at all. In any event, if we may assume such reactions to be going on between the gases as:

$$H_2 + CO_2 = CO + H_2O + 10{,}000 \text{ calories (Haber)}$$

or
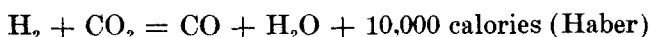
$$CO + \tfrac{1}{2} O_2 = CO_2 + 68{,}000 \text{ calories (Haber)}$$
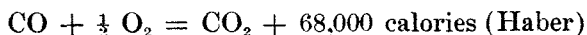
or the reaction between gas and lava:

$$3FeO + H_2O = Fe_2O_4 + H_2 + 15{,}400 \text{ calories (Chamberlin)}$$
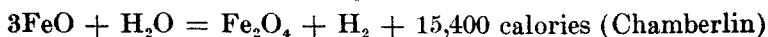
then the effect of adiabatic cooling is certainly of negligible magnitude in comparison with these. This is reasoning far beyond the data now in hand, but it serves to show that there is no cooling effect of comparable magnitude with the heating effect of the reactions going on within the active lava.

If the reactions quoted above afford a proper measure of the order of magnitude of the heat quantity thus released by chemical reaction within the tube and surface basin of the volcano, we have here happened on an enormous store of volcanic energy which reaches its maximum temperature at the surface itself. It is by no means certain at the moment that this discovery throws any new light on conditions far below the surface, except perhaps to relieve us of the necessity of postulating extreme temperatures for the lava chambers below, which on other grounds must be considered highly improbable.[1]

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[1] Whether these gas reactions may serve as a source of heat through which to point the resemblance between volcanic phenomena and geyser action (Daly) must be assigned rather to the realm of geologic speculation. At all events, the superficial phenomena at Kilauea would seem to find a serviceable explanation without requiring any of the ejecta except the gases to be of deep-seated origin. Indeed, the outbreak in May, 1912, of a lava stream from the talus immediately adjacent to the lava lake and some 40 feet above its level (pl. 10) would seem to necessitate differences of pressure, and therefore separate lava chambers, but short distances below the surface, in much the same thermodynamic relations as those supposed to exist between neighboring geysers of different height and character. Hot gases from a common source percolating through chambers, such as appear to honeycomb the Island of Hawaii, and reacting exothermally throughout their journey as actively as a Bunsen burner, would appear to offer sufficient amount and variety of power to accomplish all the visible activity now seen there.

PLATE 9.

LAVA ON THE MAIN FLOOR OF KILAUEA CRATER (JUNE 22, 1912).

About 500 meters northwest of Halemaumau.

VARIATIONS IN THE COMPOSITION OF THE GASES.

In full accord with the positive conclusion that these particular gases can not exist together in stable equilibrium at the temperature at which they are found, but are in process of active reaction, the record of the analyses shows their composition to vary from one tube to another. Successive tubes collected from the volcano at the same time (Table 2, p. 289) do not show the individual gases to be present in the same proportions, but rather in proportions which change with every bubble which bursts from the liquid basin.

VARIATIONS OF LAVA TEMPERATURE RESULTING FROM THE GAS REACTIONS.

Further confirmation of the same conclusion is found in the observation, already noted elsewhere, that when the gases given off by the lava increase in quantity (pl. 11), the quantity of lava (lava level in the basin) remaining the same, its temperature increases, and, conversely, when less gas is discharged through the lava this temperature diminishes again. During the period of our visit in 1912 this change in the temperature at the surface of the active lava in the basin amounted in maximum to 115° (June 13, 1912, 1,070°; July 6, 1912, 1,185°), and is therefore much greater than could be explained in so large a basin by fortuitous conditions of measurement. This absence of equilibrium and consequent variability of composition is also in accord with the observation of Perret and others at Vesuvius, that the relative proportions of the gases vary greatly with the condition of the crater.

EXPLOSIVE LAVAS (BRUN).

From the same viewpoint the laboratory observations of Brun on "live" or "explosive" lavas and, in contradistinction, "dead" lavas acquire new and rational significance. In all the experience of the Geophysical Laboratory with the thermal study of silicates, we have found no natural rocks or minerals which did not set free gases in considerable quantity when heated in the laboratory to a temperature high enough to melt their chief constituents. Chamberlin,[1] in his elaborate series of analyses of the gases contained in rocks, seems to have had the same experience. If these studies together represent sufficient breadth of experience to justify a sweeping conclusion, then there are no "dead" rocks, meaning thereby igneous rocks, which no longer release original volatile ingredients when heated to melting. On the other hand, if we admit the nearly or quite universal distribution of gaseous ingredients in igneous rocks, but suppose these gases were in equilibrium with each other throughout the solidification

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[1] R. T. Chamberlin: The gases in rocks. Publications of the Carnegie Institution of Washington, No 106.

period, then reheating in the laboratory could discover no "explosive" rocks. The distinction "dead" rocks and "live" or "explosive" rocks loses all significance so long as it applies merely to rocks containing gases in virtual equilibrium with each other, which merely release the gas when heated. But immediately we understand that in lavas carrying gases in solution or mechanical imprisonment the gases shut up therein may react together, with release of heat, the moment they are free to do so, "explosive" lava has a definite meaning, and Brun's experience (loc. cit., p. 55), that "once the expansion has commenced nothing [for example, withdrawal of the source of heat] can stop it," becomes a most illuminating one. Rapid expansion of the reacting gases, together with the weakening of the inclosing walls through the accession of heat thus supplied from within may very well produce explosive phenomena, in the sense in which Brun used the term, either in nature or in the laboratory. It is otherwise somewhat difficult to see how simple adiabatic expansion of a gas inclosed in walls of obsidian, which are very viscous even at very high temperatures, can produce "explosions" in the manner postulated by Brun.

WATER AND THE BASIC MINERALS.

There is another conclusion which has been freely offered by those who hold to the view that H_2O can not be present as such in the emanations from active volcanoes, of which a statement may be found in the quotation from Green in the opening paragraph of this paper. It states that " the basic minerals themselves give no indications, in the main eruptions, of having been in contact with water, *highly susceptible as they are to such an influence.*"

It appears reasonably certain that the italicized portion of this quotation (italics are ours) is dictated by the relation between basic rock, liquid water, and air at comparatively low temperatures, and to this extent it may very well be true. In the active volcano Kilauea, however, we are dealing with gaseous H_2O at a temperature above $1,000°$; this is quite another matter. It is a part of our program to endeavor to supply the lack of proper data about the relation between the several gases found and the chief ingredients of the liquid lava, and in view of the absence of such data at the present moment the question raised can receive no very complete answer. It is, nevertheless, a comparatively simple matter to bring the powdered lava and water together at $1,100°$ in the absence of oxygen. The result appears to support our view, for after several hours of the most intimate contact between the gaseous H_2O and the lava no chemical change whatever could be detected either in the "basic minerals" or the water. In so far as a qualitative experiment of this kind may

PLATE 10.

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VIEW OF THE LAVA LAKE (MAY 22, 1912).

showing a cascade, which burst from the talus pile on the northwest side of the basin but a few moments before this picture was taken   The cascade is about 10 feet high   Note the lava streams flowing from it to the left   This cascade continued to flow for three days.

PLATE 11.

VIEW OF LAVA LAKE DURING PERIOD OF MAXIMUM ACTIVITY (JULY 8, 1912).

This picture was taken at night by the light of the lava itself. Note the different directions of flow within the basin

be regarded as conclusive, this lava is not appreciably affected by water at the temperatures which obtain in the lava lake up to the time when the water leaves the lava and is discharged into the air. Pending the acquisition of more detailed data, therefore, we may leave this question in abeyance, with reasonable confidence that it will be found to be in full accord with the fact otherwise established, that water is present and participates actively in the volcanic activity at Kilauea.

ORIGIN OF THE WATER.

If we now grant that water is present as an active ingredient of the liquid lava, in view of the positive character of the evidence offered, then it becomes pertinent to inquire whether this water is of magmatic or of meteoric origin. Obviously, to this question no such positive answer can be returned as that which was offered in support of the main thesis of this paper. It is conceivable (1) that water may have entered by infiltration of sea water from the surrounding ocean, or (2) through more or less deep-seated infiltration of water originally meteoric, or, finally, (3) that it may be considered strictly magmatic in character and an original constituent of the lava.

The volcanoes of Hawaii are completely surrounded at no great distance by the sea, which rises on their flanks to a height of 15,000 or 16,000 feet, according to charted soundings and the observations of Dutton.[1] The crater of Kilauea is about 15 miles from the nearest approach of sea water, as recorded by the most modern surveys. The rock is for the most part porous in high degree. Above sea level rain falls almost daily on the island up to elevations of 7,000 or 8,000 feet. Most of this meteoric water is deposited on the windward side[2] of the mountains and the leeward portions are desert or nearly so. The Kilauea Crater is situated on the flank of Mauna Loa at an elevation of about 4,000 feet above the sea and is exactly on the ridge which separates the region of rainfall from the desert of Kau. It is somewhat misleading to assume with Dana that the rainfall at the crater is comparable with the rainfall at Hilo, the nearest considerable town where meteorologic observations are made. Hilo is to windward of the crater and at sea level. At the Volcano House, still some 3 miles to windward of Halemaumau, the rainfall tables lately published by the United States Geological Survey give the annual average for the years 1909–1911 as 78.7 inches at the Volcano House and 136.5 inches at Hilo. It is also true, though it can not yet be

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[1] C. E. Dutton: Hawaiian volcanoes. Fourth annual report United States Geological Survey, 1882–83.

[2] It will, of course, be recalled that the islands of the Hawaiian group are within the trade-wind belt, and that the direction of the wind is very nearly constant throughout most of the year.

supported by measured data, that the rainfall at Halemaumau is even smaller than that recorded at the Volcano House, for at an equal distance to leeward of Halemaumau the country is desert and practically without rainfall. The present crater lies in the midst of this transition zone from 78 inches to zero. Be that as it may, there is a more or less abundant rainfall at Kilauea, even though the aggregate amount is much smaller than has hitherto been supposed.

There is a further fact of observation which may be cited in this connection. Wells have been bored on the sugar plantations at elevations up to 2,000 feet on Hawaii and on the other islands. In these borings water is invariably met with (so far as we were able to learn) at sea level only. The water is ordinarily fresh, but a heavy draft on it always has the effect of increasing its salt content, and some of the wells have been permanently ruined for irrigation purposes by this means.

So far as the conditions surrounding this volcano are concerned, therefore, water in some form would seem to be very widely distributed except on the high mountains, and as freely available as silica for active participation in any form of volcanic activity. In the present preliminary survey of the situation it therefore appears as if any attempt to assign the water found in the lava to one or other of these three conceivable sources, or, perhaps better, to justify any specific distribution of it among the three conceivable sources, must be based on assumptions of a somewhat arbitrary and hypothetical character. Nevertheless, there are some indications which inevitably give direction to the probabilities which an individual observer may fix on. First and most important, in our opinion, is the fact that the nitrogen found in the emanation is free from argon. It is plain that if atmospheric water is to reach a hot lava column at a temperature of 1,000° or higher it must do so as a gas, and therefore on the same terms as other atmospheric gases. Argon is invariably contained in the air in measurable quantity and forms no chemical compounds. Whence it follows that if the gases of the atmosphere had reached the liquid lava in any manner whatsoever the argon would be released with the others, but no trace of argon was found.

The second difficulty is to conceive a mechanism whereby atmospheric or surface water of whatever origin (for example, the sea) can make its way into a lava column or basin at a temperature of 1,000° or more. The Daubrée experiment, whereby water vapor was found to make its way through 2 centimeters of sandstone against an excess pressure within, though often quoted in this connection, does not help us to a solution of it. The force which was active in

Daubrée's experiment is the surface tension of water only,[1] and water will obviously have no surface tension above its critical temperature of 374° (except perhaps in so far as salts in solution may have the effect of raising this critical temperature slightly). This temperature passed, water must make its way precisely like any other gas by diffusion through pores or by overcoming whatever chemical or mechanical conditions it may encounter. The prospect is not an encouraging one. The hydrostatic pressure at great depths of the sea would appear to be the only sufficiently powerful agent to drive water against a high adverse temperature gradient, but to invoke this would be to invite nice distinctions of where " magmatic " water begins and " meteoric " water ends. The presence or absence of chlorine is not a conclusive factor one way or the other, because the physical processes of infiltration through porous rock and of distillation are alike of such a kind as gradually to leave the dissolved salts behind; this is illustrated by the fact that the bore holes yield fresh water except when the infiltration is very rapid.

To us, therefore, such evidence as there is appears to indicate that the water released from the liquid lava when it reaches the surface is entitled to be considered an original component of the lava with as much right as the sulphur or the carbon.

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[1] " Capillary forces are effective only when there is a surface of separation within the pores. * * * Since the pressure discontinuity occurs only at the surface of separation, a column of liquid can be supported only when there is a free liquid surface within the capillary. * * *

" * * * As regards the influence of temperature on the surface tension of water, all the investigations unite in showing that its surface tension decreases regularly with rise of temperature, becoming zero, of course, at the critical temperature where there is no surface of separation. The relation is practically linear when the whole range is considered; it may be represented with sufficient accuracy by the formula,

$$\varsigma\, t = 78 - 0.21\, t \text{ or } 0.21\, (370 - t)$$

where $\varsigma\, t$ is the surface tension at $t°$ (temperature centigrade) expressed in dynes per centimeter.

" * * * From this * * * it is evident that the pressure producible by capillarity is insignificant in comparison with the hydrostatic pressure, except for very fine pores * * * and this minuteness of the pores leads us to inquire what amount of water could actually flow through them. * * * Assuming the mean viscosity of the water to be 0.005 (its value at a temperature of 30°), the amount of water flowing through a pore of diameter 1 μ (i. e., 1/25,000 inch) would be about 15 x 10⁻⁶ cc. per year. * * * Now, if we make the very generous estimate that 10 per cent of the volume occupied by the rock consists of pore spaces * * * the quantity of water flowing would be only 15 cc. per sq. cm. of surface per year. * * * If the diameter of the pores is 0.01 μ the amount of water flowing would be 0.0015 cc. per sq. cm. of surface per year. * * * In other words, a period of 1,000 years would be required for a quantity of water equivalent to 1.5 cms. (about one-half inch) of rain to flow past a given horizontal plane.

" * * * It appears, therefore, as if the probabilities were all against the notion that appreciable amounts of meteoric water can ever penetrate into deep-seated and highly heated rock masses." (John Johnston and L. H. Adams : " Observations on the Daubrée experiment and capillarity in relation to certain geologic speculations." Journal of Geology, vol. 22, in press, 1913.)

RIPPLE MARKS.[1]

By Ch. Épry.

[With 10 plates.]

Among the multitudinous impressions which the ebbing tide leaves
on the sands as it recedes the most curious are certainly those parallel
lines of ridges, of varying size or regularity, covering at times im-
mense areas of the beach. They are known in French as Paumelles,
which has no significance, and in English as ripple marks, which
name has prevailed, perhaps because it is foreign, or perhaps because
it is more expressive (fig. 1).[2]

Ripple marks are everywhere so common that it is impossible to
walk on any beach for a few minutes without encountering them and
admiring them, as they always present a very beautiful appearance,
especially when seen in large masses in the sunlight, although one
may suffer from them, perhaps, if one is barefooted, as they make
walking very difficult. However, although they are universally
known, no one seems until now to have definitely ascertained their
cause.

Some regard these undulations as due to the waves alone; others
consider that they are caused by the wind, by the transference of
the surface vibrations to the bottom, when these have only a little
depth of water to traverse in order to reach the latter. Learned
theories have also been formulated to explain them, none of which
give entire satisfaction.

The question still remained, therefore, "What causes the formation
of these ripple marks?" Wishing to answer it, I have taken the
opportunity, during a number of years, to observe attentively these
undulations wherever my tastes and fancy have taken me: that is
to say, from one end of our coast to the other, and the cause of the
phenomenon appears to me to-day so easy of comprehension that
I find it difficult to explain to myself why an agreement regarding
it was not reached long since. It is the very definite conclusion at

which I have arrived that I present here. Although it is simply that of an amateur who can only bring to his researches a measure of curiosity and much patience, I believe that it will impress itself on others with the same force that it has on me, if they will consent to accompany me, stage by stage, along the road which has led me to it. In order to simplify the explanation and clarify the text, I shall present in connection with each argument the most convincing of a number of photographs which I have taken on different beaches.

In the first place, then, where are these ripple marks formed? Broadly speaking, ridges of this kind are produced beyond the reach of the waves on the dry sands of the interior of dunes (fig. 2) and likewise on the sandy slopes of Sahara, or the snow carpet of Alpine heights. Due without question to æolian action, these do not interest us, at least for the present, though we shall have occasion to return to them later.

In the area in which the ebb and flow of the tides manifest themselves it is necessary to distinguish between an upper and a lower beach. The first presents a particularly steep slope, and the water only reaches it during the neap tides. But then the water possesses a much greater force, because it must, during the same number of hours, traverse a longer course. For these two reasons the layers of water which are spread out, however thin they may be, are carried about with such velocity that no other force can counteract their effects. But their action is vertical. The grains of sand are energetically propelled from below upward and from above downward, but solely in a vertical direction. Consequently, children's modelings, footprints, or ridges raised perhaps by the wind during the time when the sand is drying, all inequalities indeed, whether depressions or elevations, are erased or thrown down, as the smoothed-out slope takes on the regular surface of a glacis (fig. 3). Figure 3 shows the sea at work; figure 4 enables one to judge of the final result.

On the upper beach ripple marks are never found. They occur, in contrast, in great abundance on the lower beach, as shown in figure 1—in great abundance, but not always, nor everywhere. Figure 5 is a view taken in the Bay of Goulven on the same day and at the same hour as figure 1, and scarcely a hundred meters to the right of the place where the latter was taken and toward nearly the same point of the horizon. The two photographs placed side by side constitute a panoramic view of the same landscape. The ridges, which are so beautifully shown at the left, are irregular and scarcely outlined at the right, presenting merely a wavy appearance.

Let us go elsewhere. Here is a beach in the region of Lorient, that of Fort Bloqué, quite ideally flat, and apparently well suited for the formation of ripple marks. (See fig. 6.) A fisher woman is walking toward the rocks, which begin to appear above the water,

FIG. 1.—ON THE BAY OF GOULVEN (FINISTÈRE).

FIG. 2.—IN THE DUNES OF PARIS-PLAGE.

PLATE 2
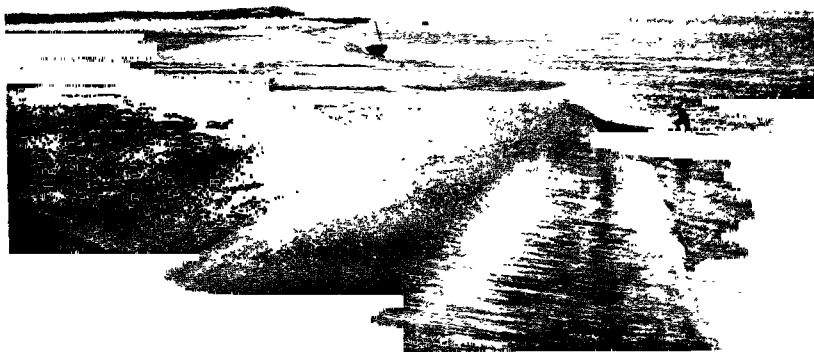
FIG. 3.—THE EBB AT CAPE FERRET, ON THE BAY OF ARACHON.

FIG. 4.—THE SEA LEAVING THE UPPER BEACH AT ETABLES (CÔTES-DU-NORD).

FIG. 5.—ON THE BAY OF GOULVEN, THE "ROC'H VRAN."

FIG. 6. —APPEARANCE OF THE LOWER BEACH AT FORT-BLUQUE WHEN THE WATER
IS RECEDING.

PLATE 4.

FIG 7.—RIPPLE MARKS BELOW LESCONIL.

FIG. 8.—STRIP OF BEACH BETWEEN POULDU AND DOUELAN.

to collect periwinkles. The water, consequently, is receding. One, however, perceives no trace of its having covered the sands. Their remarkably smooth, wet surface has the polish and the gleam of a mirror.

In contrast, in many places, especially near the time of the very low water of the spring tides—for example, on the bars that form at the mouth and along the banks of certain rivers—ripple marks are found, which, unlike those shown in figure 1, are not a few centimeters high, but 50 to 75 centimeters, or even a meter. Such ripple marks are shown in figure 7, from a photograph taken at the mouth of the Steir,[1] or lagoon of Lesconil.

As the ripple marks, then, do not form on the upper part of the beach, but are extremely common on the lower part (which corresponds in sandy regions to the zone of fucus and laminarian seaweeds of rocky shores) does it not seem that it ought to suffice, in order to discover their origin, to note the points in which the latter differs from the former? This reasoning is correct, and it is possible to draw important conclusions from this comparison. From this point of view, however, it is of importance to proceed in one's deductions with a prudent circumspection, without taking one's eyes from the facts; otherwise, one is in much danger in a moment of inattention of arriving at an explanation of the phenomenon, which, when pursued a little further, will very quickly surprise one by becoming in complete discord with all the new data acquired by observation.

What, then, is the principal difference between the two parts of the beach, from the particular point of view which we are taking? The slope of the lower beach is much more gentle, so gentle at times that the waves in certain regions recede for a distance of several kilometers in attaining the level of low water. Consequently, the velocity of the current of the tide is there very great. In the Bay of Mont-St. Michel it is equal to that of a horse galloping. On the other hand, throughout the duration of the flowing tide, the progressing stratum of water which moves up the sands is very thin, so thin, indeed, that the waves can not perpetuate themselves and die out at a considerable distance from the shore. These beaches are, while they last, like immense shallow lakes which gradually empty themselves. What is one to conclude from such a state of things? Given the slight thickness of the layer of water, it seems quite natural to believe that the action of the wind should make itself felt at the bottom, forming there ridges analogous to those which it raises on the surface of the sea. One may equally be led to inquire whether it is not necessary

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[1] The Steir is a little Breton river, which empties into the Odet at Quimper. But in that region they designate thus most of the small creeks without name that toward the ocean spread out into fjords, estuaries, or lagoons.

to attribute the formation of ripple marks to the violence of the current of the tide that sweeps this very flat area, or to the indirect action of the wind, or in some measure to the combined action of the two elements, the air and the water.

The second hypothesis has been very generally adopted. At first sight, we repeat, it appears very convincing. In reality, it does not bear serious examination, and should be resolutely rejected. Whatever the state of the atmosphere, indeed, one will observe that on a beach there are certain points where at all times, or at least with very great regularity, ridges are formed. At other points on one day they will disappear, though the wind may blow a gale, while on the morrow they reappear, though the sky may be calm and the sea like glass.

Not only is there no correlation between the movements of the aerial ocean and the wrinkling of the sandy surfaces submerged under a very thin stratum of water, but, on looking closely, one observes that it is particularly in those places where the bottom is especially protected from the influence of the wind that these marks attain their largest dimensions; for example, where the ground is accidentally sunken, in the depths of pools, or on the banks of small streams, or at low-water mark; again, where the force of the current of the tide, as well as that of the wind, whatever it may be, remains comparatively negligible, and is actually without effect, for example, on the sands of bars, which are exposed only a few minutes, and then only at the equinox, at the mouth of rivers and streams.

One should not have a shadow of a doubt on this point. Ripple marks are the work of the tide, and of that alone, as they are nowhere so numerous and conspicuous as where the sands are best protected from the effects of the wind.

This first point settled, it remains to harmonize this assertion with what we have said of the effects of the tide on the higher part of the beach, where far from producing a greater wrinkling of the bottom, the increase of its speed, owing to the great inclination of the beach, causes a general leveling.

In order to explain this apparent contradiction, and find the solution of the enigma, which of the two factors is it necessary to consider, the inequalities of the two slopes, or the difference between the dynamic effects of a breaking wave and those of a regular current? It is, in fact, neither the one nor the other. They are of no importance. All research in this direction leads to nothing. Here again is an impasse to be avoided. The solution of the problem is to be sought elsewhere. In order to discover it without further delay, we must transfer ourselves to a point on the shore where the ripple marks always, or nearly always, form; that is, to the line of

junction of the upper and the lower beach. This line of demarkation, sometimes scarcely visible, is remarkably clear in the accompanying illustration (fig. 8).

Examine this photograph closely and what do we see? A higher beach which is perfectly smooth, a lower beach, almost horizontal, equally leveled off by the sea that has withdrawn from it. Between the two, at the base of the upper slope, are two small pools quite distinctly united, of which the bottom in course of becoming dry is covered with ripple marks. Why are these ridges formed there and not higher up or farther out?

Let us pursue our examination, concentrating our attention on the nearer depression the details of which are the more distinct. In the widest part of this pool the ridges are arranged parallel with the shore, but at its extremities, situated in the nearest foreground, it is seen that these lines of ridges are directed toward the sea, diminishing in number, losing their regularity, and finally mingling together and being drawn out into a little streamlet which gradually disappears. If we could study the other pool as readily, we should discover an absolutely similar disposition of the ripple marks at the bottom of it. It also terminates in a rill. The two together seen from farther off and higher up from the top of the cliffs (fig. 9) present with perfect symmetry the appearance of a pair of French mustaches with long ends drawn down equally.

What has gone on here? It should not be imagined that hieroglyphics are more easy to decipher than these marks traced on the sand. Wherever the strand was so flat that the water could flow normally from the cliffs and toward the sea, the sandy grains, whatever might be the manner in which they were propelled, strike briskly against the waves, or the natural impulse of the tide. Whatever the inclination of the area on which they roll (in other words, whether on the lower beach as on the higher beach, as one can verify from the foregoing photograph), they are deposited in a uniform layer. They can not follow the same course in a double depression. Those which at first, when the sea strikes the plain far from the foot of the cliffs, had not the least importance end by acquiring one a little before the receding tide completely abandons them. At this moment the layers of water which sweep the depression from side to side, rise swiftly to a certain height on the slope of the upper beach, but in returning all the water can not again avoid the constantly growing obstacle which extends across its route on the progressively exposed plane of the lower beach. At the surface a part of this water still passes, but the greater portion, diverted by the knob of sand toward the middle of the pool, accumulates there seeking its level of equilibrium, and in order to find it flows out in a wavy course to the right and

left toward the two extremities, where, with the aid of the last waves, it divides into a double stream creating, in consequence, two small currents running in opposite directions parallel to the shore.

One learns from this the manner in which is formed, at this point, the deposit of sand grains carried by these currents running at right angles with the current of the tide, which brings them from the upper beach. Meeting in the pool water that possesses little force they lose their speed and are deposited. But, while they are falling to the bottom, the transverse current intervenes, turns them aside and arranges parallel with the shore this unstable, changeable mass, which is in course of formation rather than formed, and consists of these sandy particles, for the most part still suspended in the water.

Thus appear the parallel lines of ripple marks which reveal by their direction that of the secondary currents, and by their undulations the serpentine windings which are impressed on them by the vertical oscillations of the waves. Though very distinct where the divergence of the two lines of currents from an angle of 90°, the ripple marks lose little by little their regularity at a distance, and in the same measure as the forces in operation become weakened. They end by disappearing altogether in the drain where the transverse current, definitely deflected toward the sea, loses itself in the current of the tide.

Thus is this phenomenon very simply explained. In every part of the lower beach where a current runs more or less nearly at right angles with the normal current of the ebb, their combined effects inscribe themselves in ripple marks on the sand.

We arrived at this conclusion on noting the appearance which the ripple marks present when they have acquired their definite form. More convincing than any argument is the reproduction here given of a photograph showing these currents, surprised while at work and depicted in the immobility of a hundredth of a second at the moment when, under their double action, little lines of shadow stamp upon the smooth surface of the sands the first outline of ripple marks. I sought for a long time to obtain this illustration, and though a difficult task, it was finally secured.

Let us suppose that at the moment of breaking on the shore, a wave happens to strike a rock presenting a surface at an angle of about 45°. The wave, carried along by its own energy, washes this surface, and then falling down and turned aside by it, retreats to join the sea, in an elliptical course (fig. 10).

The sandy particles which it carries, as in the pool previously mentioned, are urged forward in two directions, " OA" and " OB," the one perpendicular to and the other parallel with the shore. Ripple marks should be formed there. This is confirmed by the

FIG. 9.—THE PRECEDING STRIP OF BEACH SEEN FROM A GREATER DISTANCE.
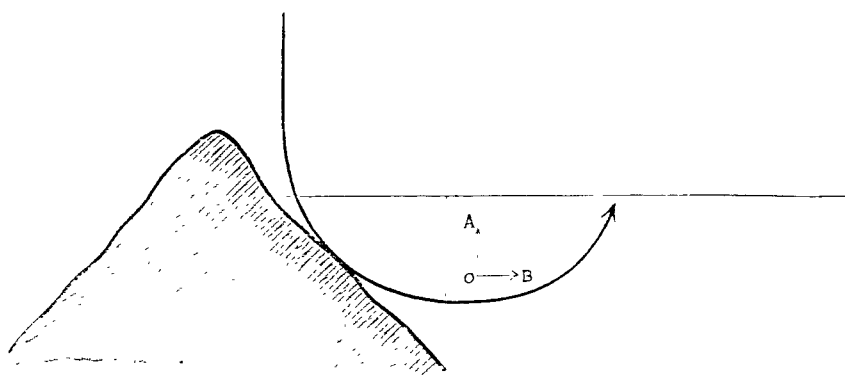
FIG. 10.—CURVE OF WAVE AFTER STRIKING ROCK.

FIG. 11.—FIRST ROUGH OUTLINE OF RIPPLE MARKS.
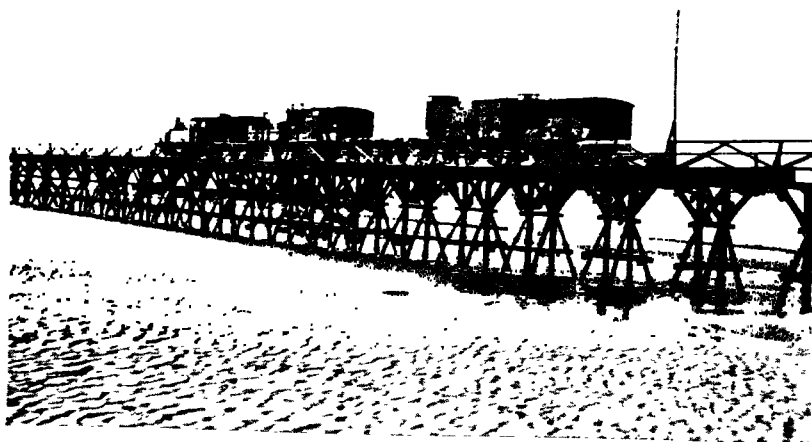
FIG. 12.—ON THE BAY OF SOMME.

accompanying instantaneous photograph (fig. 11). A wave has broken under precisely these conditions. One can discern still the contour of the fringe of foam that it spreads out on the beach. Being violently thrown from left to right, it has already abandoned the left portion. The obliquity of its course is revealed, in part, at least, by the direction of the line of shadow, which, at the right, marks the elevation which it forms on mingling with the succeeding wave, which latter at this point has not itself undergone any deviation. Where the receding wave has passed are displayed the features of ripple marks.

In general, as we have established in the bottom of our little pool at Pouldu, ripple marks arrange themselves parallel with the line of the shore, under the predominating influence of the transverse current, which draws the sands toward the outlet. On the contrary, the direction of the ephemeral marks outlined here (fig. 11) approach much more closely to a perpendicular than to a parallel with this line. The reason of this difference is very simple. It lies in the fact that this instantaneous photograph was taken on the upper beach. There only the action of the normal reflex current which levels the sand ordinarily exerts itself. It is owing to a quite special circumstance that accidentally the effects of the descending current were altered for a few seconds to a slight degree. The direction of the ridges formed express the relation between the two forces which acted together at this place.

But let us not make a point of this photographic document which was obtained with difficulty, and may doubtless appear insufficiently clear and convincing, moreover, as the jurists say, " *Testis unus testis nullus*," and as we have not been able to obtain any other evidence of this kind, we shall content ourselves with arguments derived from ripple marks which, like those of Pouldu, have acquired their definite form. In whatever place one observes them there are such numerous and harmonious evidences in favor of our theory that they appear to us irrefutable.

We now present an illustration of three conditions of the sand in the Bay of Somme (fig. 12). The waters first descended vertically down the slope of the upper beach directly toward the spectator, then at a certain moment they ran obliquely to reach the rivulet at the right, between the piles of the wharf, that should direct them toward the sea. The first slope, where ordinarily the action of the receding water alone exerts itself, is leveled. The less-inclined slope of the intermediate area, on the contrary, is covered with ridges due to a double action, the preponderating one of the transverse current and the diminished action of the normal current.

Again, in figure 13, we have, seen from above, that marvelous whirlpool of Trieux, dominated by the chateau of Roche-Jagu and its

park. Owing to an effect of shadow one can distinguish in this view all the details of the relief of the ground. They are significant. At the same time that the descending tide washes the elongated sand bank at the middle of the river from above downward water runs laterally to join it from the channel at the right and from a rivulet furrowed in the mud at the margin of the shore at the left. Ripple marks are formed at this place.

Let us now return to the great beach of Goulven, represented at the beginning of this article (fig. 1). If one introduces this view between the following (fig. 14) and that which we have given in figure 5, the accompanying panoramic view (fig. 15) will be obtained. We see at the right the shore and the most distant point of the bay dominated by a picturesque rocky mass called " The Cathedral "; at the left, stretched across the bay, a series of high granite ledges which extend above the water. The waters have receded and leveled the slope of the sands accumulated around these knobs. But directed in consequence toward the middle of the bay they have been obliged, in order to get out, to seek two lateral outlets. They have taken the direction of " F " and " F'." Do we not have here again, on an immense scale, our pool of Pouldu, with its two lateral outlets and its ridges parallel with one another and with the shore?

The similarity of the two illustrations will be better comprehended by turning again to figure 1 and examining very closely (with a magnifying glass, one might say) the smallest details of the landscape. The lines of ripple marks are drawn out over a long distance, but in reality they show at a number of points a lack of continuity. They appear to be composed of bars which follow one another irregularly, or do not stand in line at all. To summarize, this immense field of undulations may be divided into an infinity of pools similar to that of Pouldu and of banks much less important even than that of Trieux. They form a mosaic. This admirable design is effected by means of fragments and pieces, pools and banks of sand in juxtaposition, and separated by a series of parallel rivulets, some still full of water and others already completely dry, just as shown in the first illustration, where one may see at the right ridges becoming progressively deformed and losing themselves at the place where the two generating currents have taken a common direction.

The same spectacle presents itself within the bay as at its mouth. Everywhere, from whatever point we take up the question, we always arrive at the same conclusion. All these marks (with certain exceptions due to the movements of the ground, which, if we stop to study them, witness in favor of our theory) in their entirety are directed parallel to the shore toward a rapid creek formed on the right side of the bay by the retreat of the water which the sea every day carries

FIG. 13.—AN ELBOW OF THE TRIEUX.
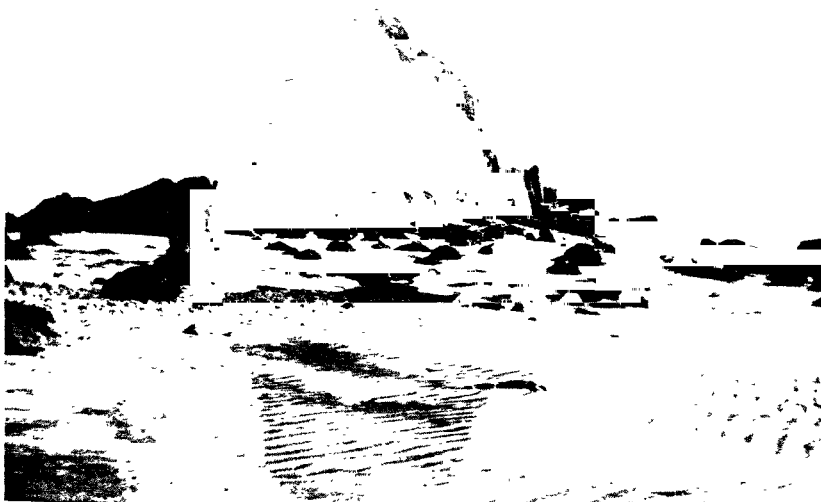
FIG. 14.—ACROSS THE BAY OF GOULVEN.

PLATE 8.
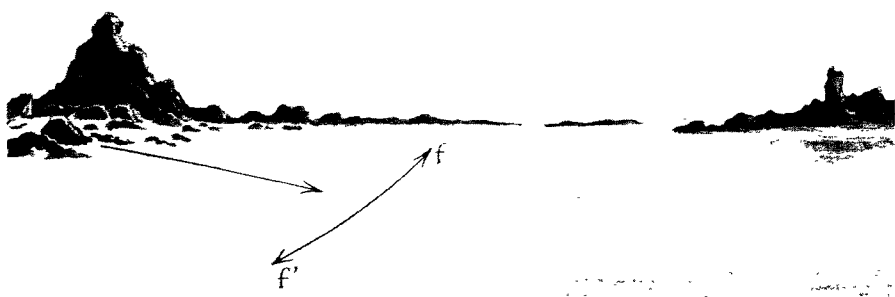
FIG. 15.—THE BAY OF GOULVEN.
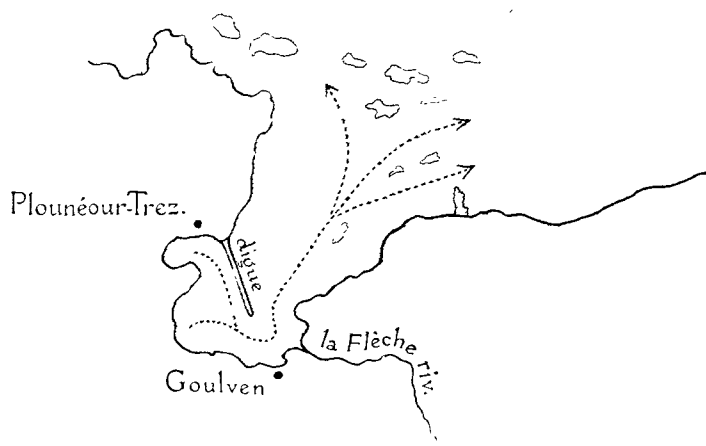
FIG. 16 —THE BAY OF GOULVEN.

to a marsh (fig. 16) that occupies, between Plounéour-Trez and Goulven, the head of the bay. If our theory be correct, one ought from the existence and direction of these ridges to conclude that the waters of the bay do not retire in a direction perpendicular to the beach, but are diverted more or less obliquely to it and toward this outlet. This is what I have always noted. One day especially, when hidden in the thicket on a sandy bar of the swamp in pursuit of herons, I killed one of these birds. The tide was high and consequently close at hand, and the bird fell into the water. As I had just eaten, it was impossible to swim out in order to recover it, and I was obliged to abandon it. The tide being high, it floated past me in a tantalizing manner. It was my first heron! When the tide had receded a little, however, the bird floated away quickly and obliquely toward the right in the direction of the creek, the outlet of all the waters of the bay. When it had arrived there it passed quickly outward and in a few minutes was lost to sight. At the same time the existence of a transverse current combining its effects with those of the ebb was revealed to me, the formation of ripple marks was demonstrated, and their direction explained by the course which the bird had followed. I had lost the specimen, but not my time.

One can understand also that ripple marks are always found cn the bar of a river, like that of the Belon, for example, which is bare during the spring tides. The mass of water which flows down from the ravine, striking against an obstacle in its path, is forced to turn laterally to seek toward the shore an easier passage; on the left, the side of the small bay of Kerfany, the real channel of the Belon; at the right, a small depression resulting from the washing out of the sands by the eddy in front of the rocks of the point of Riec.

We may now return to the furrows in the dry sand of the dunes, or in the snow on the mountains. It will be observed that whatever the agency, air or water, the process is always the same. The ripple marks are never formed on the surfaces exposed to the full current, but always in the gullies, or on the side of slopes over which the current of air descends obliquely. Their direction indicates the course of the current (fig. 17).

On the contrary, where no transverse current intervenes ripple marks are lacking in the places in which one might have expected to find them. Our angle of the beach at Fort Bloqué (fig. 6) is without them, because the peninsula which serves as an embankment to the fort prevents the access of all currents parallel with the shore, that of Coureau passing between the Lorient section of the mainland on the east, and the island of Groix. The ebb is produced there normally. The ripple marks appear solely at a point lower down and farther from the shore, outside the protected zone. Can it be said

that they never form in the angle? Not at all. I have seen them sometimes, but when a strong wind from the west forces the water to the right, parallel with the shore into the depressions of the embankment.

I could multiply the examples indefinitely, accumulating the evidences, but this article would then be nothing more than an album of photographs. I shall not dwell on the evidence further, considering sufficiently demonstrated a fact that anyone, if I have failed to remove his doubt, can easily confirm on any beach. In concluding, I desire to return to two secondary points, but not unimportant ones, which, after mentioning incidentally, I put aside temporarily in order to first settle the principal questions. The secondary questions relate not to the mode of formation of ripple marks but to their location and the differences that are observed in their dimensions in the various places in which they appear.

Ripple marks, as I have observed, form only on the lower beach, and there again not in all places nor at all times. I will explain why none are seen in the photograph taken on the beach at Fort Bloqué. To account for their absence in this part of the bay of Goulven, shown in figure 5, which includes all portions of the ripple-mark field, it is necessary to take notice of a factor that has not as yet been mentioned. This is the nature of the bottom. Here we encounter a layer of mud and not of sand. It is not necessary to seek for any other reason why the ripple marks are absent. They do not form on muddy bottoms. Such bottoms, which are very compact because composed of very fine particles, oppose to the attack of the tide a resistance all the more effective as their surface is viscous and gummy. The sea strikes them without finding more to take hold upon than the wind finds on a surface of water protected by a film of oil. A current may, however, if it be very violent, leave some trace of its passage, but indistinct and of little importance. In place of ripple marks one observes that kind of choppy appearance, like the coagulations in a semiclear soup, which one sees in figure 5. It is of interest to compare the effects produced by the same current under exactly the same conditions in two places near Lesconil, distant scarcely 100 meters from one another, in the one case on mud (fig. 18) and in the second on sand (fig. 7).

Between the mainland and the island of Oléron the rapid current of Maumusson produces on the coarse sands from the point of Menson to the St. Trojan landing, ripple marks of enormous size in the furrows of which on the days of the spring tide one spears sole, turbot, plaice, torpedoes, and gurnards. But beyond this landing there extends an immense field of mud divided into separate masses in front of St. Trojan, unfrequented and inaccessible from

PLATE 9.

FIG. 17.—SAND DUNES IN THE DESERT OF SOUTH TUNIS.

(Photographed by Lehnert and Landrock, Tunis.)

FIG. 18.—MUD BOTTOM IN THE STIER OF LESCONIL (FINISTERE).

FIG 19.—DESERT OF MUD AT LOW TIDE BETWEEN THE MAINLAND AND THE ISLAND OF OLERON.

the harbor of this locality and stretching all along the island as far as Ors, Le Château, and beyond. The layer of mud, constantly accumulating by the accession of fragments of shell derived from the oyster beds, attains a thickness of from 60 centimeters to 1 meter and more. In figure 19 is shown lying exposed to the sun at low tide the surface of this desert of mud and the marks which indicate the currents flowing from the Straits of Maumusson and Antioche. It is impossible to recognize a trace of ripple marks there, although the place is scarcely 200 meters from the point of Menson and its ripple marks, and is affected by the same current.

Ripple marks, then, do not occur in pure mud. They are only formed on the sand, of whatever purity it may be. Although very muddy, as especially in the same locality, on the beaches of Angoulins, the sands cover it very easily. The bank with ripple marks, which we have already noticed in Bretagne in the river Trieux, was of a muddy sand, as is evidenced by the bright reflection of the sunlight on its surface.

It may be asserted that these undulations are nowhere so fine and sharp as where the currents find in suspension in the water which they propel enough clay to cement the always crumbling sandy materials of these ephemeral structures. If the sand is very pure, the grains roll too easily on one another and are prevented from coming to rest on the sides of the furrow. Such ridges consequently have a wider base and proportionately less height than ripple marks of a smaller size formed on bottoms that are slightly muddy. If the sand is not only pure, but of very large grains, such as is encountered, for example, at Penmark, at Guilvinnec, and at Langoz, or again south of Concarneau from the point of Jument to that of Trévignon, then the ripple marks are formed with great difficulty. They occur here only under the influence of very strong currents and attain in this case very remarkable dimensions.

From this circumstance I am led to formulate the last of the observations that I shall present, to wit, their dimensions are always in direct relation to the force of the currents that form them. If in the bay of Goulven, after having taken the view No. 1, with the coast of Plouescat for the horizon line, I had made a half turn and had advanced 200 or 300 paces in a new direction toward Brignogan, I should have photographed ripple marks twice the size of those shown in figure 1. It is in this place that the creek that serves as the outlet of the marsh and bay passes through, much increased in breadth and lacking depth, though still rapid. During the whole time of the ebb, the entire strength of the current bears on this point, and the ridges on the coarse sands transported there reach an exceptional size.

In the same manner may be explained the dimensions of the ripple marks on the bar of the Belon. By itself the Belon does not exist as a river. Close to its mouth toward Riec and Moëlan, in the vicinity of Guilly, it is—

> A small brook, scarcely appearing to flow.
> A thirsty giant drinks it up at a breath.

But between the two resisting ledges of granite the ocean has furrowed in its direction landward a passage or fjord, at the outlet of which, between the points of Riec and Kerfany, this brook in the open sea takes on at the hour of the ebb the proportions and the force of an impetuous river. Its sound is considerable, and the depth of the channels furrowed in the sands of the bar measures its power, just as the size of the ripple marks formed opposite the point of Menson reveal the currents that flow around the island of Oléron.

To summarize, I shall formulate the following conclusions:

1. Ripple marks are due entirely to the action of water.

2. They are never formed on the upper beach nor on entirely muddy bottoms.

3. They appear on all parts of the lower beach, where, on the sandy bottom, a transverse current cuts across the normal current of the ebb.

4. They are aligned in the direction of the transverse current. Their direction, if they deviate, expresses the relation of the two forces which are in action.

5. Their dimensions are a function of the nature of the bottom, the size of the grains of sand, and the velocity of the water.

NOTES ON THE GEOLOGICAL HISTORY OF THE WAL-NUTS AND HICKORIES.[1]

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The walnut family (Juglandaceae), which in the popular mind is fully rounded out by the enumeration of the walnut, butternut, hickory, and pignut, while relatively small, is by no means as limited as this might indicate. According to current interpretations there are 6 genera and about 40 species widely scattered throughout the warmer parts of the North Temperate Zone and penetrating some distance south of the Equator along the Andes in South America, and in the East Indies.

The Juglandaceae are of considerable interest for a variety of reasons, chief among which, aside from their great economic importance, are their long line of ancestors reaching back some millions of years to the mid-Cretaceous, and the former wide range and abundance of these ancestors, which also serves to explain the curious geographical distribution of the still existing species. They are also interesting because of the much discussed question as to whether their morphological characters shall be interpreted as primitive or as mere simplifications of a more highly organized stock.

Not all of the genera have adopted the same methods of seed dispersal and certain genera have kept the seed part of their fruits comparatively small and light, thus enabling them to produce large numbers of seeds with the same expenditure of energy required for a single walnut. Furthermore, instead of depending altogether upon chance for the dissemination of their latent progeny, the bracts which are normally present have developed enormously and serve as wings. This is especially true in the genera *Engelhardtia* and *Oreomunnea* and will be referred to on a subsequent page.

The fruits unmistakably indicate the genera—those of the hickory have smooth shells and a husk which splits more or less, the walnuts and butternuts have a very rugose surface and an entire husk, while *Engelhardtia, Oreomunnea,* and *Pterocarya* have small compound winged fruits. The leaves are always compound, indicating a trop-

ical ancestry, as was first enunciated by Grisebach. They may be distinguished from those of the ash by being alternately arranged instead of opposite. There are numerous other details which enable the student to distinguish between the leaves of the different genera and species. It will be convenient to take up each genus separately and describe something of its present range and such portion of its geologic history as is known.

THE GENUS HICORIA.

The hickories are now referred to the genus *Hicoria*, proposed by Rafinesque in 1808, although many systematists, especially in the Old World, still use the name *Carya* proposed by Nuttall in 1818 and universally used until about 20 years ago.

The hickories occupy a unique economic position, for while the consumption of this wood is less in quantity than that of some of the other hardwoods such as white oak or yellow poplar, or of various coniferous trees like the cypress or the pines, it shares with the black walnut the distinction of being the most costly American wood. Hickory, while not remarkable for beauty of color or of grain, will probably be the most difficult wood to replace when the approaching shortage becomes more acute, since it combines weight, hardness, stiffness, strength, and toughness to a degree unequaled among commercial woods. The Forest Service estimates that the consumption of hickory for lumber, spokes, tool handles, rims, shafts, sucker rods, etc., amounted to 450,000,000 board feet during 1908, exclusive of the large amount used as fuel, estimated at about 1,000,000 cords—for hickory is also the best American fuel wood.

The genus *Hicoria* is entirely confined to North America in the existing flora, more particularly to the eastern United States, although there is an indigenous species in Mexico (*Hicoria mexicana*), and three or four other species reach their northern limit of growth beyond the Great Lakes in eastern Canada.

The existing species number from 8 to 15, according to the rank assigned to the varieties of the 8 or 9 easily distinguished and main types. They fall naturally into two groups—the true hickories and the pecan hickories—groups which were already clearly defined in preglacial Pliocene times.

The true hickories are fine, slow growing trees of in general temperate dry soils with hard strong wood. The buds are full, with overlapping scales, and the nuts are generally thick shelled and thick husked, while the leaflets are from three to nine in number. The pecan hickories are trees which require warmth and moisture, and possess relatively weak wood. The buds are thin and narrow without overlapping scales and the nuts have thin shells and thin husks while the leaflets are numerous, slender, and falcate.

Over a score of fossil species have been described. Unlike the walnut the hickory is not known with certainty from the Cretaceous, but it is present in very early Eocene deposits in Wyoming and on the Pacific coast. Hickories occur in the upper Eocene of
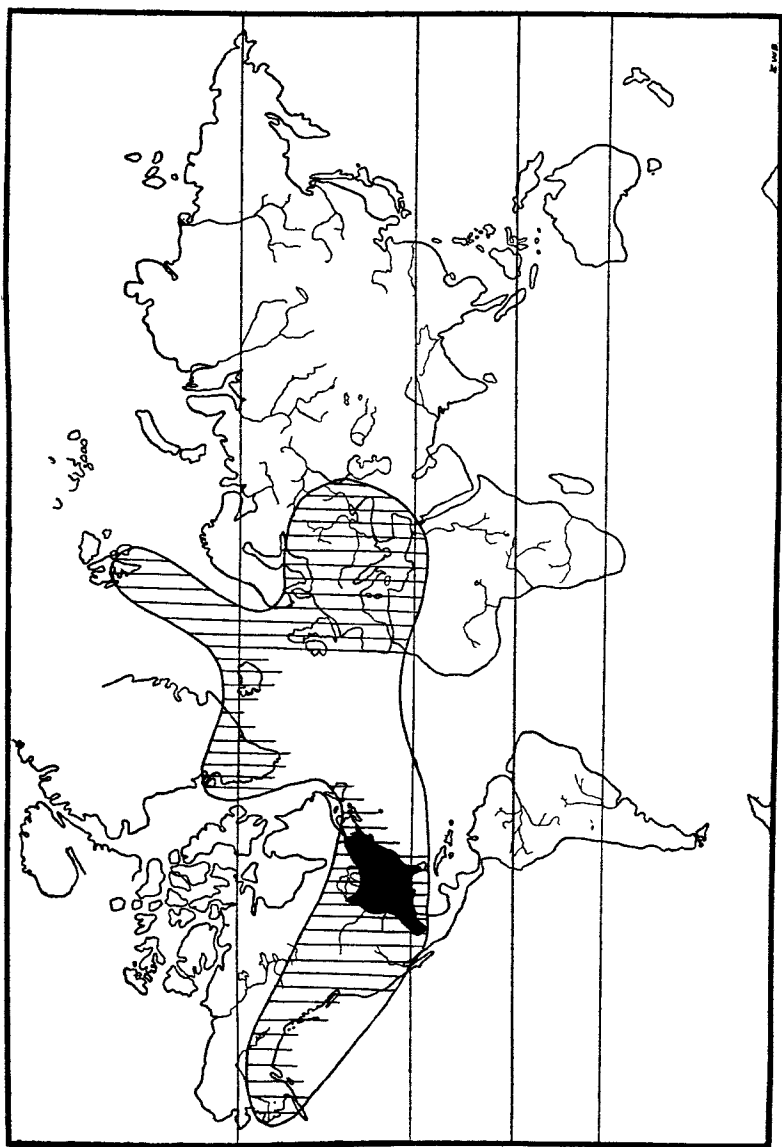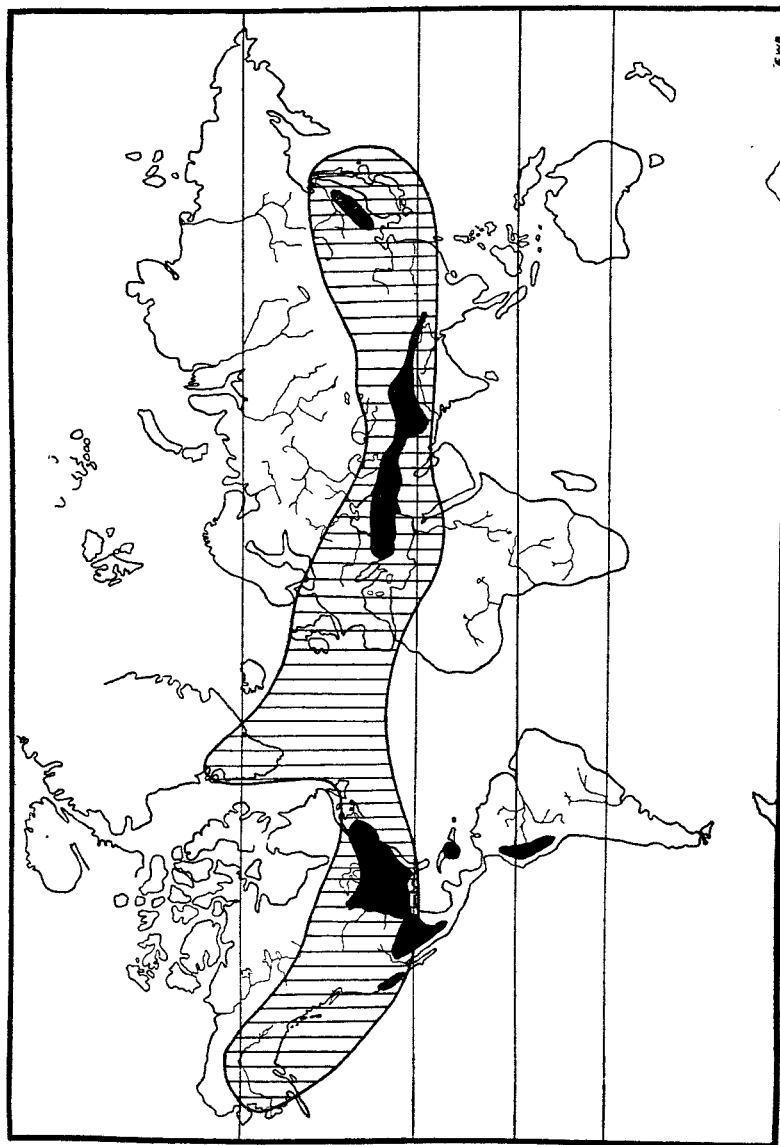
FIG. 1.—Sketch map showing the area of distribution of the existing species of *Hicoria* (solid black) and the area over which the genus is known to have spread during its past history (vertical lining).

Central Europe and there is a fine large leafed species from deposits of this age at Kukak Bay, Alaska. The Oligocene occurrences are largely referred to *Hicoria ventricosa* which is abundantly represented by leaves and fruit in the Oligocene browncoal deposits

of Europe. The late Miocene appears to have been the period of widest extent of the hickories. From deposits of this age about a dozen species are known. Trees were scattered all over Europe and the genus extended to Iceland, Greenland, and Spitzbergen. In North America there were species in Oregon and California, in Colorado and in Vermont. A species very close to the existing pecan occurs in the late Miocene of New Jersey.

During the succeeding Pliocene period the hickories are as abundant and vigorous as in the late Miocene in Europe although their northern limit appears to have become somewhat restricted. Even as late as the Upper Pliocene several species of hickory are abundant in Italy and Germany, but none survived the ice age on that continent.

A species resembling the pecan is represented by both leaves and nuts in a late Pliocene lagoon deposit in southern Alabama. In America there are numerous Pleistocene records, the leaves being preserved in the clay deposits of the river terraces and the fruits in the buried swamp deposits. The following still existing species are recorded from the Pleistocene of this country; *Hicoria pecan* from the old Mississippi bluffs at Columbus, Ky.; *Hicoria alba* from a cave in Pennsylvania, and from the interglacial beds near Toronto, Canada; *Hicoria aquatica* from North Carolina; *Hicoria ovata* from Pennsylvania, Maryland, and North Carolina; *Hicoria villosa* from Alabama; and *Hicoria glabra* from Pennsylvania, Maryland, Virginia, and North Carolina.

The accompanying map (fig. 1) shows the area occupied by the existing species in solid black and the known Tertiary range by vertical lining. It seems probable that the genus spread eastward over Asia, but the latter continent has been so little explored that no records are known.

While the Ice Age exterminated the hickories from Eurasia, the genus survived safely in North America and is in no danger of extermination except by the ax of the woodman. Their great tolerance of shade and their ability to respond to the stimulus of increased light, combined with their longevity, are important factors in their continued existence. While the rodents consume many of the fruits, they have probably done so during the whole history of the genus, for nuts gnawed by squirrels are not infrequent in Pleistocene deposits. This is not an unmixed evil, for various rodents not only distribute the species but bury the nuts in forgotten places, where they are almost sure to grow. Before the advent of the " civilized ax " many venerable old giant hickories were scattered through our American forests and there are numerous records of immense trunks showing 350 or more annual rings.

THE GENUS JUGLANS.

The name *Juglans* is a contraction of *Jovis glans*, or nut of Jupiter, and the specific name of the species known to the ancient Greeks and Romans is *regia*, or royal, and is fittingly applied to the magnificent tree which has been so commonly planted throughout the Old World for so many centuries. Nuts are found under the Swiss lake dwellings of the Neolithic period. Our two eastern American species are equally royal trees. The black walnut, *Juglans nigra* Linné, ranges from Massachusetts to southern Ontario, Minnesota, and eastern Kansas, and southward to Florida and Texas. Its rich edible fruits are unsurpassed among nuts and the handsome dark wood has made it a favorite wherever furniture is manufactured, and in consequence the tree is becoming scarce. It makes a fine growth when planted abroad, and undoubtedly was a native of Europe in preglacial time, as is shown by nuts preserved in the Pliocene deposits of that country, which are indistinguishable from the existing species. The butternut or white walnut, *Juglans cinerea* Linné, yields a wood that is much inferior to the black walnut, but its fruit is equally attractive. It ranges somewhat farther to the northward and not so far to the southward as the black walnut, being found from New Brunswick and Ontario to North Dakota and southward to Delaware. In the Alleghanian region it extends southward to Georgia and northeastern Mississippi and it is also found in Arkansas. It is distinctly not a coastal-plain species. Like the black walnut, it is very closely allied to certain preglacial European forms. There are several other American species with a more limited range. They are all trees, and include a Jamaican form and one or two species found in the Andes of Bolivia. A species of northern Mexico, *Juglans rupestris* Engelmann, extends into Arizona, New Mexico, and the Rio Grande part of Texas, and there is a single species, *Juglans californica* Watson, along the Pacific coast in California. The range of the latter is limited and its seedlings are scarce, the nuts being largely consumed by rodents. There is also a species of walnut on the opposite shore of the Pacific in Manchuria.

The genus Juglans is apparently one of the earliest of the still-existing dicotyledonous genera to appear in the fossil record, leaves suggesting it having been found in the middle Cretaceous. It is well represented in fossil flora from the base of the Upper Cretaceous to the present, the former horizon furnishing at least seven species, one of which, *Juglans arctica* Heer, ranges from Greenland to Alabama along the Atlantic coast and furnishes a striking illustration of the difference between Cretaceous and present-day climates.

There are about 25 Eocene species of walnut well distributed over the Northern Hemisphere. They extend from the Mexican Gulf

region to Alaska and Greenland in North America and from Saghalin . Island, off the east coast of Asia, to western Europe in the Old World.

The Oligocene walnuts are not quite so plentiful as are those of the Eocene and are almost entirely confined to the Old World. This is undoubtedly an expression of the incompleteness of the geological record in North America, since there are practically no known Oligocene plant beds in this country.

The Miocene has furnished upwards of two score species, the majority of which are Old World forms, distributed from Japan to western Europe. This again is due more to lack of records in America than to the absence of the genus. In this country nuts are preserved in the curiously isolated lignite deposit near Brandon, Vt. There are species in Idaho, several in California and Oregon, and four in Colorado in the late Miocene at Florissant. Both fruit and leaves are frequently found associated in the various Tertiary deposits and nuts also occur with the leaves in some of the Cretaceous deposits.

The Pliocene species are also numerous, a number of them surviving from Miocene times. In all, about 25 forms have been recorded from the Pliocene deposits, and several of these are very close, if not identical, with still-existing species. From the Upper Pliocene of Germany nuts have been collected in the lignite deposits which are exactly like those of the existing American species *Juglans nigra* and *Juglans cinerea*.

Walnuts are not common in Pleistocene deposits but the fruit of *Juglans regia* Linné is recorded from the Pleistocene of southern France, and our own black walnut, *Juglans nigra* Linné, has been found in the late Pleistocene of Maryland and in the Pleistocene river terraces of Alabama. Both of these occurrences are based upon the characteristic nuts preserved in the impure peat of buried swamp deposits.

The walnut of Europe, *Juglans regia* Linné, while extensively planted in southern Europe as well as throughout the Orient, is only endemic in Greece[1] and eastward through Asia Minor, Transcaucasia, the northwestern Himalayan region, and in northern Burma.[2]

In recent geological times its range has probably become greatly restricted, since the oldest known occurrence of forms identical with the modern tree are in the latest Miocene deposits of central France. A considerable number of occurrences have been recorded from the Pliocene deposits of this region, and the central plateau of France was evidently clothed with a considerable stand of walnut in preglacial times. During the Pleistocene this species is known from a

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[1] Mentioned from Greece in Theophrastus and occurrence confirmed in recent years by Heldreich and others.

[2] Possibly also in the mountains of northern China and Japan

number of localities in northern Italy, in Hanover, and in southern France (Provence), while the nuts found associated with the Swiss lake dwellings were undoubtedly obtained from wild trees of the immediate neighborhood.

FIG. 2.—Sketch map showing the area of distribution of the existing species of *Juglans* (solid black) and the area over which the genus is known to have spread during its past history (vertical lining).

The manner in which the fossils enable us to obtain a vista into the life of bygone days is furnished by recent discoveries in the Egyptian desert. At a time (latest Eocene or earliest Oligocene) when Libya was separated from Europe and Asia by a vast Mediter-

ranean sea the Fayum was a delta with a heavy rainfall (as shown by the flora), clothed with forests of an Indomalayan type and inhabited by ancestral elephants and other curious forms of ancient animal life. No less than eight kinds of figs, as well as laurels and camphor trees, have been described from this now arid and desiccated region. Among these fossil plants are the remains of a species of walnut, a striking commentary on the changes which have since taken place.

I have attempted to give a graphic summary of the present and past range of the walnuts on the accompanying sketch map (fig. 2), where the areas of distribution of the existing species (somewhat exaggerated) are shown in solid black. It is possible that the part of the range of *Juglans regia* in southern Asia should be extended eastward over Tibet, through northern China to Japan. All of the known fossil occurrences of walnuts have been plotted and are inclosed within the vertically lined area. Probably the boundary of the southward extension of the genus should be extended, at least sufficiently far to include the South American existing species. It is readily apparent from this map that the modern segregated species are isolated remnants of a once world-wide distribution and that the glacial epoch was an unimportant incident in their history on the North American continent, while in Europe it greatly restricted the range of *Juglans regia* and altogether exterminated one or two additional species of the walnut.

THE GENUS ENGELHARDTIA.

The genus *Engelhardtia* was described by Leschen in 1825 and contains about 10 species of the southeastern Asiatic area. These range from the northwestern Himalayan region, where they extend a short distance north of the Tropic of Cancer through farther India and Burma to Java and the Philippines. The pistillate flowers are small and are grouped in paniculate spikes. They develop into small drupe-like fruits, each of which is connate at the base to a large expanded trialate involucre.

A single little-known species, rarely represented in even the larger herbaria, occurs in Central America and is the type and only species of the genus *Oreomunnea* of Oersted. This is much more restricted in its range than are its kin beyond the Pacific. *Oreomunnea* is very close to *Engelhardtia*, and for the purposes of the paleobotanist the two may be considered as identical, since they represent the but slightly modified descendants of a common ancestry which was of cosmopolitan distribution during the early Tertiary. The present isolation of *Oreomunnea* furnishes a striking illustration of the enormous changes which have taken place in the flora of the world

in the relatively short time, geologically speaking, that has elapsed since the dawn of the Tertiary.

The principle has frequently been enunciated that when closely related forms are found in the existing flora of the world, restricted in range and isolated from their nearest relatives, or when other existing genera are monotypic, it is quite safe to predict an interesting and extending geological history. *Engelhardtia* proves to be another illustration of this principle, for its peculiar three-winged fruits have been known in the fossil state for almost a century. They were long unrecognized, however, and the earlier students who described them compared them with the somewhat similar winged fruits of the genus *Carpinus* (Betulaceae). With the botanical exploration of distant lands in the early part of the nineteenth cen-
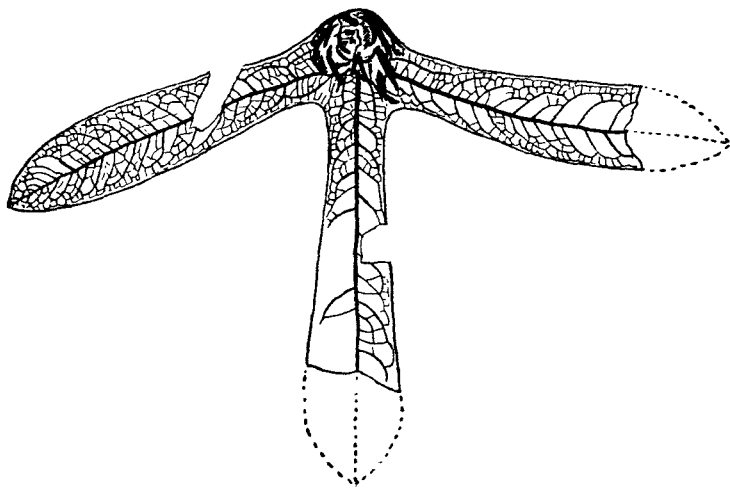
FIG. 3.—*Engelhardtia* (*Oreomunnea*) *mississippiensis* Berry, from the lower Eocene of Mississippi (natural size).

tury, specimens of *Engelhardtia* began to be represented in the larger European herbaria, and Baron Ettingshausen, that most sagacious of paleobotanists, as long ago as 1851 pointed out that certain supposed species of *Carpinus* were really fruits of *Engelhardtia*. He returned to the subject in 1858 without, however, actually changing the names of any of the supposed species of *Carpinus*, nor does he seem to have been aware of the existence of a living species of *Engelhardtia* (*Oreomunnea*) in Central America.

Since Ettingshausen's announcement a dozen or more fossil species have been described. The oldest known European form occurs in the upper Eocene or lower Oligocene (Ligurien) of France, and the species become increasingly abundant throughout southern Europe

especially toward the close of the Oligocene and the dawn of the Miocene, Saporta stating that the slabs from the leaf beds at Armissan in southeastern France are thickly strewn with their peculiar fruits. Fossil forms continue in Europe throughout the Miocene
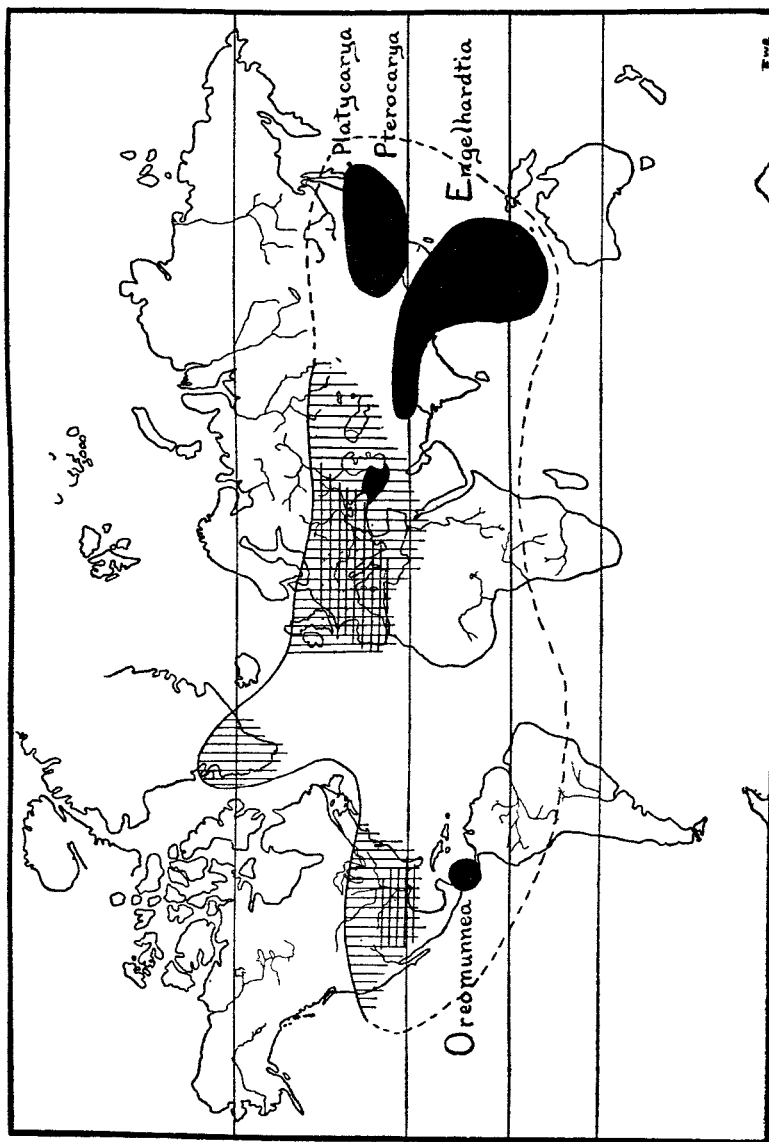
FIG. 4.—Sketch map showing the area of distribution of the existing species of *Engelhardtia*, *Oreomunnea*, *Platycarya*, and *Pterocarya* (solid black) and the area over which they are known to have spread during their past history, *Pterocarya* indicated by vertical lining and *Engelhardtia* (including *Oreomunnea*) by horizontal lining.

and Pliocene, and specimens of late Miocene or early Pliocene age are recorded from Spain, France, Italy, Croatia, and Hungary.

The only described species from America occurs somewhat earlier than any of the European forms, being found in the lower Eocene

(Wilcox group) of northern Mississippi. The type figure of this form is reproduced in figure 3. This is not the only known species from America, however, as fossil leaves of this or other species occur at the same horizon, and an additional species with smaller fruits has recently been discovered by the writer in the middle Eocene (Claiborne group) of southern Arkansas.

The accompanying sketch map (fig. 4) shows the existing area of distribution of the genus *Engelhardtia* in the Orient and *Oreomunnea* in the Occident in solid black. These areas are somewhat generalized and exaggerated in order to be visible on so small a scale map.

The areas where Tertiary species of *Engelhardtia* have been found are covered by horizontal lining, and while not as extensive as might be desired, indicate very clearly what was stated a few paragraphs back, that forms closely allied to the modern *Engelhardtia* were widespread during the Tertiary period when the more extensive warm climate enabled them to penetrate more than half way across the North Temperate Zone. It seems probable that they also pushed southward into the South Temperate Zone, but we can not verify nor disprove this theory since practically no fossil plants of Tertiary age have been discovered in South America, Africa, or Australia. Another probability is that careful exploration will disclose the living representatives of this widespread Tertiary stock in western Brazil, especially as they have survived in Central America north of the Equator.

In a general way *Engelhardtia* fruits are not unlike those of *Carpinus*. There seems to be little occasion for confusion, however, even in poorly preserved fossil material. The fruit proper is decidedly different, although this is seldom well enough preserved in fossils to be decisive. The involucre is also markedly different in the two genera. *Carpinus* involucres are usually smaller, with the median wing much wider and longer than the lateral wings and with somewhat different venation.

The margins are also toothed, while in *Engelhardtia* they are always entire. I have examined fruits of all the existing species of *Carpinus* and experience no difficulty in readily distinguishing them from those of *Engelhardtia*, the American species of the former being especially different in appearance from those of *Engelhardtia*. I have seen involucres of the Old World *Carpinus betulus* from trees cultivated in this country in which the wings had entire or nearly entire margins, but the aspect of the specimens as a whole, because of their different proportions and venation, was markedly unlike *Engelhardtia*, and if they had been found as fossils no competent paleobotanist would have been at a loss regarding their botanical affinity for a single instant.

THE GENUS PTEROCARYA.

The genus *Pterocarya* was described by Kunth in 1824. It is made up of three or four species with very circumscribed ranges. The type *Pterocarya caucasica* A. Meyer (*P. fraxinifolia* Spach.) at present is confined to a limited area in trans-Caucasus, while another species occurs in northern China and one or two in Japan, as shown in a greatly exaggerated way in the solid black areas on figure 4.

The determination of the fossil species from their leaves is beset with difficulties, but the fruits are perfectly characteristic and have been found in a number of instances.

The oldest known fossil species is recorded from the Tertiary of Colorado, and while the American material that can be referred to this genus is not abundant at any period the genus undoubtedly occurred on this continent during the later Tertiary. One record is from deposits as late as the early Pleistocene, but this is not based upon positively identified material.

In Europe the records of *Pterocarya* commence with the Oligocene. The Tertiary species are numerous and widespread, the abundant *Pterocarya denticulata* Heer being found from Bohemia and Transylvania through Germany, Switzerland, and England northward to western Greenland. This widespread species which continues unabated throughout the Pliocene period is thought to be the direct ancestor of the existing *Pterocarya caucasica*. There are at least five additional Miocene species.

The Pliocene species are numerous and abundant, and are found all over southern Europe, being especially common along the elevated shores of the extended Mediterranean Sea, in the plateau region of central France, and in the Apennines of Italy. The still existing *Pterocarya caucasica* makes its appearance in the plateau region of central France at this time where it is represented by both leaves and the characteristic fruits. It still grew in Netherlands in the early Pleistocene, according to Dubois, but was apparently exterminated during the glacial period. It is also known from the Altai Mountains of Central Asia in deposits of this age. In figure 4 the known range of the fossil species is shown by vertical lining. It seems obvious from the distribution of the ancestral forms and the very circumscribed range of the few living descendants that the genus is approaching extinction.

THE GENUS PLATYCARYA.

The genus *Platycarya* was characterized by Siebold and Zuccarini, who have described so many oriental plants. It is a monotypic genus; that is to say, it contains a single existing species, which was the basis of the genus *Fortunaea* of Lindley. This single species is a

small tree of Japan and northern China, and its range is roughly shown on the accompanying map (fig. 4) in solid black. Monotypic genera usually have a very interesting geological history, as, for example, *Sassafras*, *Comptonia*, *Ginkgo*, and many others. However, no fossil remains of *Platycarya* have been discovered, and this is probably due to the fact that the vast continent of Asia is practically unexplored.

<div align="center">CONCLUSION.</div>

Forestry experts warn us that commercial hickory is growing scarce, just as the black walnut is already scarce. Aside from our enjoyment of their fruits and the very special practical ends which the wood fulfills we should not forget the sentiment which attaches to a family of such magnificent trees, a family with an ancestry, as we have just seen, extending back millions of years to a far-off time when the dominant animal population of the globe was the uncouth reptiles of the Cretaceous, a time when the evolution of the mammalia had not yet been wrought out, and when man was a far-distant promise, not even hinted at in the teeming life of that age. While we can never hope to bring back the primeval forests of our ancestors, we can use the intelligence which has been so slowly acquired through the ages in conserving these magnificent tree relics of bygone ages.

THE FORMATION OF LEAFMOLD.[1]

By FREDERICK V. COVILLE.

When the leaves of a tree fall to the ground they begin to decay and ultimately they are disintegrated and their substance becomes incorporated with the other elements of the soil. The same thing happens with the leaves, stems, and roots of herbaceous plants. Such organic matter is one of the chief sources of food for plants, and its presence in the soil is therefore of fundamental importance in the maintenance of the vegetative mantle of the earth.

In a series of experiments from 1906 to 1910 the speaker showed that a condition of acidity is a primary requirement of the blueberry (*Vaccinium*), laurel (*Kalmia latifolia*), trailing arbutus (*Epigaea repens*), and other plants associated with them in natural distribution. Other kinds of plants and plant associations require, on the contrary, a neutral or alkaline soil.

It is the purpose of the present address to show how the leaves of trees in the process of the formation of leafmold produce at one time or under one set of circumstances a condition of soil acidity, at another time or under other circumstances a condition of alkalinity, and after calling attention to the acidity of the soil as a fundamental factor in plant ecology, to point out that a knowledge of certain phenomena in the decay of leaves is essential to a correct understanding of the distribution of vegetation over the surface of the earth and its adaptation to the uses of man.

In the early experiments with blueberries it had been found that these plants grew successfully in certain acid soils composed chiefly of partially rotted oak leaves. On the rather natural assumption that the more thorough the decomposition of this material the more luxuriant would be the growth of the blueberry plants, some old oak leafmold was secured for further experiments. It had been rotting for about five years and all evidences of leaf structure had disappeared. It had become a black mellow vegetal mold.

When blueberry plants were placed in mixtures containing this mold they did not respond with luxuriant growth. On the contrary their leaves turned purple and afterward yellowish, their growth dwindled to almost nothing, and at the end of the season when compared with other blueberry plants grown in a soil mixture in which the oak leafmold was replaced by only partially decomposed oak leaves the plants in the oak leafmold were found to weigh only one-fifth as much as the others. This astonishing result is exactly contrary to the ordinary conception. We have been accustomed to believe that the more thoroughly decomposed the organic matter of a soil the more luxuriant its vegetation. In this case, however, thorough decomposition of the soil was exceedingly injurious to the plants.

This remarkable difference in effect between partially decomposed and thoroughly decomposed oak leaves was found to be correlated with a difference in the chemical reaction of the two materials, the partially decomposed oak leaves being acid, when tested with phenolphthalein, and the oak leafmold alkaline.

With rose cuttings and alfalfa seedlings in the same two soils exactly opposite results followed, those in the oak leafmold making a luxuriant growth, those in the partially decomposed oak leaves showing every sign of starvation.

Every botanist is familiar with the rich woods where trillium, spring beauty *(Claytonia),* mertensia, and blood root *(Sanguinaria canadensis)* delight to grow, in a black mellow mold made up chiefly of rotted leaves. He is familiar, too, with the sandy pine and oak woods where grow huckleberries *(Gaylussacia),* laurel *(Kalmia latifolia),* princess pine *(Chimaphila),* the pink lady's slipper *(Cypripedium acaule),* and trailing arbutus *(Epigaea repens).* The soil here also is made up chiefly of rotting leaves and roots. Yet one does not look for trilliums in laurel thickets, or for arbutus among the bloodroots. Either habitat is utterly repugnant to the plants of the other.

Tests of the two habitats show that the trillium soil is alkaline, the other acid, reactions corresponding exactly to those observed in the cultural experiments already described, rose cuttings and alfalfa requiring an alkaline soil, blueberries an acid soil. The difference is as conspicuous in nature as in the laboratory and the greenhouse.

What are the conditions under which rotting leaves develop these opposite chemical reactions?

In a ravine in the Arlington National Cemetery, near Washington, where the autumn leaf fall from an oak grove has been dumped year after year for many years, every stage in the decomposition of oak leaves may be observed, from the first softening of the dry

brown leaf by rain to the black mellow leafmold in which all traces of leaf structure have disappeared. When freshly fallen the leaves show 0.4 normal acidity.[1] Those not familiar with the chemical expression " normal acidity " may perhaps most readily understand the term by reference to ordinary lemon juice, which has very nearly normal acidity in the chemical sense. Fresh oak leaves may be conceived therefore as having about one-third the acidity of lemon juice, gram to cubic centimeter. From a soil standpoint such a degree of acidity is exceedingly high. Probably no tree or flowering plant could live if its roots were imbedded in a soil as acid as this. A correct appreciation of the excessive acidity of freshly fallen leaves enables one to understand why it is that the leaves of our lawn trees, if allowed to lie and leach upon the grass, either injure or destroy it. On such neglected lawns the turf grows thin, mossy, and starved.

From the height of their initial acidity it is a long descending course through the various stages of leaf decomposition to the point of chemical neutrality, and then upward a lesser distance on the hill of alkalinity, in the black leafmold stage.

In order to ascertain the rate of decomposition in leaves of various kinds, observations were begun in the autumn of 1909 on leaves of silver maple (*Acer saccharinum*), sugar maple (*Acer saccharum*), red oak (*Quercus rubra*), and scrub pine (*Pinus virginiana*), exposed to the weather in barrels and in concrete pits. In one experiment a mass of trodden silver maple leaves 2 feet in depth, with an initial acidity of 0.92 normal, was reduced in a single year to a 3-inch layer of black mold containing only a few fragments of leaf skeletons and giving an alkaline reaction. In these experiments sugar maple leaves have shown a slower rate of decomposition than those of silver maple, while red oak leaves still show an acidity of 0.010 normal after three years of exposure, and leaves of Virginia pine an acidity of 0.055 normal under the same conditions.

The alkalinity of leafmold is due chiefly to the lime it contains, the lime content expressed in terms of calcium oxid often reaching 2 to 3 per cent of the dry weight. One sample had a lime content of 2.55 per cent. Many of the soils that result directly and exclusively from the decomposition of limestone have a lower percentage of lime than this. An alkaline leafmold containing 2 to 3 per cent of lime is properly regarded as a highly calcareous soil. Yet such a deposit may be formed in a region where the underlying soil is distinctly non-calcareous, the lime content of the soil being only a small fraction of 1 per cent and the soil reaction being acid.

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[1] In the acidity determinations, made by Mr. J. F. Breazeale, phenolphthalein was used as an indicator, the carbon dioxid having been first boiled off. For a full description of the method followed, see Coville, 1910, p. 27, Experiments in blueberry culture, Bulletin 193, Bureau of Plant Industry, U. S. Department of Agriculture.

Whence comes the abundance of lime in an alkaline, richly calcareous leafmold formed over a soil distinguished by an actual poverty of calcareous matter?

If the leafmold is rich in lime the leaves from which it is derived should also be rich in lime. A determination of the amount of calcium oxid in the dried freshly fallen leaves of some of our well-known trees shows this to be true, as illustrated by the following selections: [1]

Kind of leaves.	Per cent of calcium oxid.
Red oak (*Quercus rubra*)	1.73
Silver maple (*Acer saccharinum*)	1.88
Pin oak (*Quercus palustris*)	1.91
Sweet gum (*Liquidambar styraciflua*)	1.92
Bur oak (*Quercus macrocarpa*)	2.39
Elm (*Ulmus americana*)	2.50
Sugar maple (*Acer saccharum*)	2.56
Tulip tree (*Liriodendron tulipifera*)	2.84
Hickory (*Hicoria myristicaeformis*)	3.66
Gingko (*Ginkgo biloba*)	4.38
Basswood (*Tilia americana*)	4.50
Orange (*Citrus aurantium*)	6.77

These analyses show that the amount of lime in the leaves of trees is often astonishingly large.

It should be understood that the lime does not exist in the leaf in the form of actual calcium oxid. It is largely combined with the acids of the leaf and serves in part to neutralize them, but is insufficient in amount to effect a complete neutralization. In all the kinds of leaves and herbage thus far examined the net result is an acid condition, although lime may be present in large amount. Thus in the leaves of silver maple a condition of excessive acidity exists, about 0.9 normal, notwithstanding the presence of nearly 2 per cent of lime.

As the decomposition of such leaves progresses the acid substances are disorganized and largely dissipated in the form of gases and liquids, while the lime, being only slightly soluble, remains with the residue of decomposition, the black leafmold, and renders it alkaline.

In soils poor in lime, trees and other plants constituting the vegetative mantle of the earth may be regarded as machines for concentrating lime at the surface of the ground. This lime is drawn up by the roots in dilute solution from lower depths, is concentrated in the foliage, and the concentrate is transferred to the ground by the fall and decomposition of the leaves. The proverbial agricultural fertility of the virgin timberlands of our country was undoubtedly

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[1] The lime determinations were made by Mr. J. F. Breazeale, of the Bureau of Chemistry, Department of Agriculture.

due in large part to the lime accumulated on the forest floor by the trees in preceding centuries, and to the consequent alkalinity of such surface soils when the timber had been removed and the leaf litter was thoroughly decomposed. After a generation or two of reckless removal of crops the surface accumulation of lime was depleted and unless the underlying soil was naturally calcareous a condition of infertility ensued, which, for the purposes of ordinary agriculture, could be remedied only by the artificial application of lime.

The chief agents in the decay of leaves are undoubtedly fungi and bacteria. There are other agencies, however, that contribute greatly to the rapidity of decay. Important among these are earthworms, larvæ of flies and beetles, and myriapods or thousand-legged worms. Animals of all these groups exist in myriads in the leaf litter. They eat the leaves, grind them, partially decompose them in the process of digestion, and restore them again to the soil, well prepared for the further decomposing action of the microscopic organisms of decay.

The importance of earthworms in hastening the decay of vegetal matter was pointed out long ago by Darwin in his classical studies on that subject. The importance of myriapods, however, as contributing to the formation of leafmold has not been adequately recognized. In the canyon of the Potomac River, above Washington, on the steeper forested talus slopes, especially those facing northward, the formation of alkaline leafmold is in active progress. The purer deposits are found in pockets among the rocks, where the leafmold is not in contact with the mineral soil and does not become mixed with it. The slope directly opposite Plummers Island is a good example of such localities. Here during all the warm months the fallen leaves of the mixed hardwood forest are occupied by an army of myriapods, the largest and most abundant being a species known as *Spirobolus marginatus*. The adults are about 3 inches in length and a quarter of an inch in diameter. They remain underneath the leaves in the daytime and emerge in great numbers at night. On one occasion a thousand were picked up by Mr. H. S. Barber on an area 10 by 100 feet, without disturbing the leaves. On another occasion an area 4 by 20 feet yielded 320 of these myriapods, the leaf litter in this case being carefully searched. Everywhere are evidences of the activity of these animals in the deposits of ground-up leaves and rotten wood. Careful measurements of the work of the animals in captivity show that the excrement of the adults amounts to about half a cubic centimeter each per day. It is estimated on the basis of the moist weight of the material that these animals are contributing each year to the formation of leafmold at the rate of more than 2 tons per acre.

The decay of leaves is greatly accelerated also when the underlying soil is calcareous and alkaline, it being immaterial whether the

lime is derived from a limestone formation or is a concentrate of the vegetation. On the rich bottom-land islands of the upper Potomac the autumn leaf fall barely lasts through the following summer, so rapid is its decay. These bottom lands have an alkaline flora, and they are found to have an alkaline reaction, caused by the lime brought to them in the flood waters.

The acceleration of leaf decay by an alkaline substratum is due to prompt neutralization of the acid leachings of the leaves and also to the fact that such a substratum harbors with great efficiency many of the most active organisms of decay, from bacteria to earthworms.

It must not be understood that in a state of nature the decomposition of leaves is always so simple and uniform a process as has been described, or that it always results in the formation of an alkaline leafmold. The chief factors that contribute to the acceleration of leaf decay have already been enumerated, but there are other conditions of nature that obstruct and retard this process. Under certain conditions the progress of decomposition may be permanently suspended long before the alkaline stage is reached. The soils thus formed, although high in humus like a true leafmold, have an acid reaction and a wholly different flora.

Examples of such suspensions of leaf decay are found in bogs, where the deposited vegetation is protected from the organisms of decay by submergence in nonalkaline water, and on uplands where the soil is derived from sand, sandstone, granite, or schist, in which there is not enough lime or other basic material to neutralize the acidity of the decaying leaves.

There is, of course, a supply of lime in the leaves themselves, and as a new layer of leaves is added to the soil each year it might be expected that there would result an unlimited concentration of lime in the surface soil and that all surface soils that supported a growth of vegetation would ultimately become alkaline. Such an indefinite accumulation of lime is prevented, however, by another factor which requires consideration. As soon as each successive layer of leaf litter is sufficiently decayed to permit the roots of plants to enter it and feed upon it, the lime it contains, together with other mineral constituents, begins to be absorbed. This loss of lime from the decaying leaves is sufficient, under many situations in nature, to prevent the decaying mass from reaching the alkaline stage. Decomposition is suspended while the leaf litter is still acid. True leafmold, with an alkaline reaction, is never formed under such conditions. The leaf deposit remains permanently acid and such areas bear an acid flora. In the vicinity of Washington one often sees hills of quartz gravel, wind swept and rain washed, where the soil contained little lime in the beginning and none could be brought by flood waters or by the dust of the atmosphere. Characteristic plants

of such hills are black jack oak (*Quercus marilandica*), trailing arbutus, wild pansy (*Viola pedata*), azalea, and huckleberry, all plants adapted to acute conditions of acidity. If one's front yard happens to coincide with what was once such a spot, let him not undertake the herculean task of growing roses and a bluegrass turf. Let his lawn be of redtop and his shrubs be azaleas, laurel, and rhododendrons.

Another factor that contributes to the suspension of leaf decomposition is the acid leachings from each new deposit of autumn leaves. Various acidity determinations show that after lying exposed to the weather over winter, leaves ordinarily have only one-fifth to one-tenth the acidity they possessed when they fell to the ground. It has been found experimentally that the leachings from fresh leaves will serve to acidulate an underlying soil of moderate alkalinity. Unless, therefore, the conditions of a locality are such as to effect the decomposition of one year's leaf fall before the next year's deposit takes place, a permanent acid leaf cover is established. In many of the oak forests on the sandy coastal plain eastward from Washington there is a permanent accumulation of such material. The roots of the trees and undershrubs bind the half-rotted leaves into a dense mat. The principal trees are oaks. The principal shrubs that make up the dense underbrush belong to the Ericaceæ and related families. There is no mellow leafmold nor any of the leafmold plants.

This kind of mat or turf is of such widespread occurrence, is so distinct in its appearance, and so characteristic in the type of vegetation it supports that it should have a name of its own, in order that it may come to be recognized as one of the important phenomena of nature.

Because of its resemblance to bog peat in appearance, structure, and chemical composition, and because it supports a type of vegetation similar to that of bog peat it has been proposed to adopt for it the name upland peat. As defined in an earlier publication,[1] upland peat is "a nonpaludose deposit of organic matter, chiefly leaves, in a condition of suspended and imperfect decomposition and still showing its original leaf structure, the suspension of decomposition being due to the development and maintenance of an acid condition which is inimical to the growth of the microorganisms of decay."

Upland peat would have become leafmold had not the orderly normal course of leaf decomposition been suspended and conditions of acidity established which rendered the further progress of that decomposition impossible.

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[1] Coville, 1910, p. 34. Experiments in blueberry culture, Bulletin 193, Bureau of Plant Industry, U. S. Department of Agriculture.

The rate at which leaves decay is greatly influenced by temperature. In the cooler northern latitudes and at high elevations in lower latitudes the rate of decay is slower and the formation of upland peat is more general than in warmer climates. Except on calcareous soils the higher Appalachian peaks, from 4,000 to 6,000 feet, bear an almost continuous layer of upland peat, from a few inches to a foot or more in depth. Their great rhododendron thickets are rooted in deep beds of upland peat. The spruce forests of the higher New England mountains lay down a similar formation.

In the treeless West the decay of leaves where it is not actually suspended by dryness is rapid and complete. At the higher elevations, however, where the land begins to be timbered the organic matter does not fully decay, and in the heavily timbered areas the deposit of upland peat often becomes characteristically deep and continuous. In fighting creeping fires in the yellow pine forests at the lower elevations the favorite and most effective tool is the rake, which parts the light leaf litter and puts a stop to the progress of the flames. But in the dense fir and spruce timber the forest ranger's chief tools are the spade and the mattock, with which he must cut through the thick layer of dry peat to the mineral soil beneath if he is to effectually combat a slowly creeping fire.

So strong is the tendency to the formation of peat under the low temperatures and heavy precipitation of the high mountains that even on limestone soils a superficial layer of upland peat is sometimes accumulated. Such a condition exists on innumerable areas at an elevation of about 10,000 feet in the Manti National Forest of Utah. On the basaltic plateau of extreme northeastern Oregon, where the soil is naturally alkaline in reaction the lodgepole pine and Douglas fir forests at elevations of 5,000 feet and over lay down a continuous bed of peat which supports a characteristic acid flora. A quantitative test of one of the acid flora soils of this region, at an elevation of 8,000 feet, showed the customary high acidity at the surface, and successively lower degrees of acidity underneath, until at the depth of 5 feet, at the surface of the basaltic rock, the reaction was neutral.

The group of plants that forms the best index to the acid character of a soil is the family Ericaceæ, and the related families Vacciniaceæ and Pyrolaceæ. When these occur in vigorous growth on a calcareous soil or among calcareous rocks, as is sometimes reported, one may expect to find, as the speaker in his own experience has always found, that a layer of upland peat has been formed above the calcareous substratum and that in this superficial layer the roots of the plants find their nourishment, really in an acid medium, notwithstanding the alkalinity beneath.

Continued observations on the association of certain types of wild plants with acid and nonacid soils, supported by cultural experi-

ments, are in all respects confirmatory of the theory that soil acidity is one of the most influential factors in plant distribution and plant ecology.

The relation of leafmold to the existence of acid or nonacid soil conditions may now be viewed with appreciative recognition. If the conditions in any area are such that the decay of leaves follows the uninterrupted course that leads to the formation of leafmold a state of soil alkalinity is reached, with all the resultant effects on the growth and distribution of the native vegetation. If, on the other hand, the conditions are such that the course of decay is diverted into the channel that ends in the formation of peat, a condition of permanent acidity is indicated, with the accompaniment of all those peculiar plant phenomena which are characteristic of such a state.

It is perhaps desirable to call attention here to the fact that while partially decomposed vegetation appears to be the chief source of soil acidity, there are mineral constituents of the soil, of wide distribution and great abundance, which are also acid in reaction. The acidity of which we hear so much in agricultural writings as characteristic of soils worn out by long years of careless farming is doubtless due in large part to a natural mineral acidity unsheathed by the removal of the lime that once neutralized it, for, like the leaves of trees, many of the crops of agriculture are heavy with lime and their uncompensated removal year after year has its inevitable cumulative result.

The speaker hopes that he does not overstep the proper bounds of this address if he calls attention to conditions in bog deposits which almost exactly parallel the two types of terrestial organic formation, leafmold and upland peat. In bogs with alkaline waters, as, for example, those underlain by marl, a condition of permanent acidity is not maintained in the lower strata of the deposit. As far upward as the alkaline waters penetrate, the antiseptic acids are not present, decay continues, and the resulting formation is not peat, but a plastic fine-grained black material that may best, perhaps, be designated by that much misused term, *muck*. Muck corresponds in bog deposits to leafmold in upland deposits, contrasting with bog peat as leafmold contrasts with upland peat.

We may follow this idea one step further. Coal is petrified peat. As the purest peats are not formed in alkaline waters, it can not be expected that the best coal will be found in situations indicative of alkaline conditions. If coal is found immediately overlying beds of marl or limestone it is to be expected that such coal will be of an impure type, corresponding in origin to muck. The speaker takes the liberty of suggesting to his geological friends that in reconstructing in theory the climatic and other conditions under which the

various kinds of coal were deposited they may safely hypothesize that the purer coals were laid down in waters that were acid.

Allusion has been made to the peculiar characteristics of plants that inhabit peat. Among these peculiarities perhaps none is more remarkable than the presence of mycorhizal fungi on the roots of many, perhaps most, peat-loving plants. It is known that peat is very poorly supplied with nitrogen in the form of nitrates, which most plants of alkaline soils appear to require. Organic nitrogen, however, is abundant in peat, and there is very strong evidence that these mycorhizal fungi take up this organic nitrogen, and probably atmospheric nitrogen also, and transfer it in some acceptable form to the plants in whose roots they live. Unfortunately, the work of botanists on these fungi has been confined largely to the determination of the mere anatomical fact of their occurrence on the roots or in certain of the root cells, with descriptions of their size and configuration. Little attention has been paid to the isolation of the fungi, their culture and identification, or to the demonstration of their physiological action. The only hypothesis, however, that satisfactorily explains what we already know about the mycorhizal fungi is that they prevent the nitrogen starvation of peat-inhabiting plants. It is well known that certain peat-bog plants, as, for example, sundew (*Drosera*), trap insects, digest them, and assimilate their nitrogen. It is to be hoped that within a few years we shall be equally well informed about the function of the mycorhizal fungi. But even now we may speak of their probable function with confidence.

The mycorhizal fungi are known to occur on most of the trees that inhabit acid situations, for example, chestnut, beech, oaks, and conifers. The ordinary hillside pasture in New England is a mycorhizal cosmos. The club mosses have them, the sweet fern (*Comptonia*), the blueberries, the ferns, the orchids. In our sandy pine and oak woods about Washington almost all the vegetation possesses mycorhizal fungi. One comes to think of the giant oaks as dependent on these minute organisms.

Were Solomon to write a new edition of the Proverbs to-day I am sure that he would tell us " There be four things which are little upon the earth, but they are exceeding strong," and that among the four he would include " The little brothers of the forest, they seek not the light but the leafy earth: they prepare for the oak the strength that is his."

Our American agriculture, derived in the main from the agriculture of the Mediterranean region, and that in turn from the older agriculture of Persia, is chiefly made up of plants that thrive best in alkaline or neutral soils. Although many of our soils in the eastern United States are naturally acid, we try with only indifferent success to grow in them these alkaline plants of southern Europe and the

East. Although some of our agricultural plants are tolerant of acidity, our agriculturalists have not yet recognized the possibility of building up for acid soils a special agriculture in which all the crops are acid-tolerant. We may yet, perhaps, utilize for agricultural purposes even the sandy acid lands of the coastal plain instead of turning them over as we now do to the lank huckleberry picker, whose lonesome garden is all that he is able to reclaim by present methods from the imaginary wilderness that surrounds him. Yet these lands contain all sorts of delicious native fruits, and a natural vegetation rich and luxuriant after its own manner.

Had our agriculture originated not in the alkaline soils of the Orient, but among the aboriginal peoples of the bogs of Scotland, or of the sandy pine barrens of our Atlantic Coastal Plain, we should have entirely different ideas of soil fertility from those we now possess. If our cultivated fruits were large and otherwise improved forms of the blueberry, the service berry (*Amelanchier*), the thorn-apple (*Crataegus*), and the beach plum (*Prunus maritima*), if our only grains were rye and buckwheat, and our only hay redtop and vetch, and if our root crops consisted of potatoes and carrots only, our high-priced agricultural lands would be the light sandy acid soils and the drained bogs, while our deep limestone soils would be condemned to use for the pasturage of cattle and of sheep.

Thus far man has devoted himself largely to the utilization of the plants of the leafmold, which have gathered up for him the wealth of the earth. Let him now, I say, turn his attention also to the plants of the peat and try whether they will not yield to him in increased measure the luxuriance of foliage and of fruit that they have always yielded without assistance to nature herself.

THE DEVELOPMENT OF ORCHID CULTIVATION AND ITS BEARING UPON EVOLUTIONARY THEORIES.[1]

By J. COSTANTIN.

When crowds throng our horticultural exhibitions they are struck chiefly by the brilliant splendor of color, the rich variety of forms, and the strange transformations produced in the vegetable kingdom by the art of the plant breeder; but they are often incapable of appreciating the true importance of all the wonders displayed before their gaze. Even a philosopher who had a profound knowledge of the affairs of nature would find, in a visit to such an exhibition, material for reflections of deep import, and the conclusions resulting from his inspection would deserve the attention of the public at large and of all men who think.

Unfortunately, the philosopher rarely takes the pains to acquire the knowledge possessed by the specialist, and the specialist generally concerns himself but little with general theories, with the result that all those who seek knowledge remain in ignorance. Let us attempt, despite the difficulty of the subject, to assist them in their search.

To render our task less difficult let us limit our attention to the most brilliant corner of the exposition, and everyone will understand at once that we are to speak of that devoted to the orchids. It is, in fact, the section where the visitors are most numerous; it is there that they see the most beautiful flowers and sometimes the most strange ones, and it is there that we find the part whose significance the public understands least.

What at once strikes anyone who examines the orchids is the bizarre aspect of these plants—their slender forms, their thick, fleshy leaves, their aerial roots, their bulbous bases, all contrasting with the incomparable brilliance of their corollas. Everyone still feels something of the sensations, so well described by de Puydt,[2] which were experienced by visitors to the orchid houses long ago when these

[2] De Puydt, Les Orchidées, p. 16.

plants were beginning to be grown in numbers in Europe: "You would enter the house full of orchids with eager curiosity, as though it were some shrine where a tangible mystery was to be unfolded. The method of growth without soil, the aerial roots, the heavy atmosphere, the abnormal leaves, the strange aspect, would grip you all at once, and if blossoms were open with their peculiar forms, fleshy petals, somber colors, and penetrating perfumes, you stood overwhelmed at the display and at the patience of the gardener."

What used to cause so much astonishment at the method of growth of orchids resulted from a peculiarity of these plants which was then little understood. namely. that they are children of the air, or, in other words, epiphytes. In Europe we know but little of plants of this class, for we have only the lichens and mosses upon the trunks of our trees to give us any idea of them. In the warmer regions of the globe, on the contrary, this mode of existence is widespread, and for many ages the seeds of certain species, embracing sometimes almost entire families, like the orchids and bromeliads, have been able to solve victoriously the delicate problem of existence imposed upon an organism compelled to live and grow upon the branch of a tree, exposed to the burning rays of the sun, which strive to scorch it, and in great danger of dying from starvation in consequence of lack of food to supply its demands. This epiphytic life attracted the attention of Osbeck, who collected plants in Asia and Malaysia for Linnæus in the eighteenth century. He sent the latter a great number of curious types, which were all described by the celebrated Swedish botanist under the name of Epidendrum, he, wishing to denote thus by the generic name the fact that they had the common characteristic of growing upon trees.

A Portuguese missionary, Loureiro, a distinguished botanist who studied the flora of Indo-China, was very strongly impressed by the habit of growth of *Aerides odoratum*, which lived "freely suspended in the air with neither food nor any base, either terrestrial or aquatic." In 1812 Loddiges. publishing the first catalogue of orchids cultivated in the hothouses of Hackney. England. declared that he had received *Oncidium ensifolium* from a traveler returning from Montevideo. who had seen the plant flower, deprived of all soil, in the cabin he occupied on shipboard.

Horticulturists tried from the first to reproduce artificially the conditions for aerial life. and it is thus that the celebrated Joseph Banks, in 1817, described the first attempts at culture in frames suspended from the roof of the greenhouse. Treatment of orchids in pots with some sort of earth, which had been the method employed in the first attempts at cultivation at the end of the eighteenth century, was altogether barbarous and inevitably resulted in the death

of the delicate aerial plant. No one would think of making a fish live out of water. How could one expect that a species accustomed to a free epiphytic life would accommodate itself without injury to a low terrestrial existence?

The proper mode of cultivation once found was perfected little by little. For certain types found exclusively in the tops of trees there was devised a plan of fastening them to a piece of wood with brass wire together with a little moss to furnish permanent moisture. An aquatic moss, sphagnum, seemed particularly suited to fill this rôle because of its power of imbibing water. It was in 1841 that Paxton first mentioned it as having been employed by him in the Duke of Devonshire's greenhouses. It remained to discover the compost commonly employed for most orchids, which consists of an intimate mixture of sphagnum and fibers of fern roots (peat of the English, Osmunda, Polypodium), after these two elements have been finely cut, this mixture covering fragments of broken pots used to furnish drainage (potsherds placed in the lower part of the receptacles in which the plant is put). But all the tropical orchids are not aerial, as was soon learned, and when the lady's-slippers arrived to furnish the handsomest ornaments of European greenhouses they were cultivated in pots, for they were terrestrial plants, a little fresh earth being added in their case to the compost which suited most orchids.[1]

There was no thought of cultivating species accustomed to a tropical climate except in very warm greenhouses: and in 1830 Lindley, who contributed so much to the progress of the science of orchids, insisted upon the necessity of maintaining for cultivated types the two factors which characterize equatorial climates—heat and humidity. It was immediately after this that the technique was perfected which made it possible to obtain in greenhouses an elevated temperature along with an atmosphere charged with vapor to the point of saturation by frequent sprinkling not only of the plants but of the walks, walls, and benches, thus reproducing artificially the constant rains, the torrents which descend almost daily upon many equatorial countries.

Unfortunately this method of treatment, which succeeded wonderfully with certain plants, resulted, with many others, in lamentable failure. Lindley and other horticulturists in 1830 agreed that all tropical plants are accustomed to a uniform climate. but beneath the

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[1] A recent and important perfection of this method consists in treating differently the species which live in calcareous soil and those which shun it. The latter should be moistened with rain water if the running water of the region where they are grown contains lime (as is usually the case in France) ; and as potsherds for drainage pieces of broken flower pots are used. In the case of species preferring calcareous soil, like *Cypripedium bellatulum, concolor, niveum, Godefroyae,* drainage is furnished by pieces of mortar: in addition, pieces of calcareous rocks are mixed with the compost, and the plants are moistened with ordinary water.

Equator it is necessary only to ascend the slopes of a mountain to see the climate change. The mountain species of warm regions should not be treated like essentially tropical plants that are accustomed exclusively to elevated temperatures. There are plenty of orchids, and not the least beautiful ones, which grow in the neighborhood of snow in regions where the thermometer falls to zero. The explorations of Skinner in the cordilleras of Guatemala; of Gibson in India, notably on Khasia Hill; of Gardner in the Organ Mountains of Brazil; of William Lobb in the Peruvian Andes; of Mottley in the mountains of Java, gave information almost simultaneously, about 1835, of the wonderful flowers which bloom at high altitudes. From this same year dates an important discovery by Joseph Cooper, the skilled gardener of the Earl of Fitzwilliam. According to him orchids had often been cultivated at too high a temperature, and the mistake had been made, from fear of cold, of keeping them in air-tight houses; thus frequently they had been suffocated, for in the confined atmosphere, charged with carbon dioxide, life became very difficult, and it was indeed remarkable that failures had not been more frequent. The methods of cultivation recommended by Cooper tended gradually to classify greenhouses in three categories, according to the temperature maintained in them—hothouses, temperate houses, and cold houses. The last are to-day graced with plants of the first rank, among which must be mentioned first the Odontoglossums, which rival Cattleyas in the beauty of their flowers. It was not until 1863 that the most remarkable species of the genus, *Odontoglossum crispum,* was introduced. This plant was sent simultaneously by three collectors who were ardent explorers of the same regions of America—Weir, Blunt, and Schlim—who traveled separately, the first for the London Horticultural Society, the second for the English horticulturist, Hugo Low, and the third for the Maison Linden, of Belgium. This " steeplechase " for the introduction of an orchid shows that in Europe there was a violent attempt made and a considerable expenditure of effort upon all sides to add a marvel more to the greenhouses.

One may conceive from the account of such exertions that the growing of orchids had received a great impulse. All the great commercial houses at once employed explorers to search the less known and least accessible countries for all the rare species, and by thousands the orchids began to flow into Europe. Travelers profited by the dormant period of the plants during the dry season to remove the epiphytes from their supports and ship them in cases, as if they were dry or dead objects. The traffic thus inaugurated at the beginning of the nineteenth century has been continued to the present time, and to indicate its importance I need cite only a single figure, which is sufficiently eloquent and significant: There are large horti-

cultural establishments in England which import every year from one hundred to two hundred thousand plants.[1]

The reader may perhaps ask, when he reads these fantastic figures, why so much labor is expended, and he will think that it would be much easier to sow the seeds, which can be obtained by the thousands. This is exactly what all the horticulturists tried to do in the early days of orchid culture, but all their attempts were without result, and for a long time the secret of germination was unknown. The seeds have peculiar characteristics that are not found in those of other plants. They are extremely small, without albumen, inclosed in a tegument, and formed of a simple minute mass of similar, undifferentiated cells. The minuteness of the seeds is compensated for by their great number, and a mature capsule contains an enormous number of seeds, which are described as scobiform, they being thus compared to sawdust. Evidently if it had been known how to make the seeds germinate, orchids could have been multiplied in a prodigious fashion, and they would have become among our commonest plants. That they have not become so is because for a long time it was impossible to revive life in the seeds. We read in an important work published in 1822 by the French botanist Du Petit Thouars, who distinguished himself by the study of the orchids of Bourbon and Madagascar: " It was believed for a long time that the seeds were incapable of the first act of vegetation, and it is only a short time since that Dr. Salisbury has observed it in England." Dr. Salisbury's discovery seems to have been purely accidental, and when other observers attempted to repeat his experiment they met with complete failure. Nevertheless, as the nineteenth century went by, examples of germination attributable to chance multiplied, but no one knew of any method tending to reproduce the phenomenon with certainty. However, some keen observer, whose name has remained unknown[2] to science, unless it may be Dominy, who will be mentioned later, noticed that the accidental and infrequent germination took place on the compost surrounding the mother plant or, better still, on the roots which were in the compost but projected more or less completely from it. This observation, the result of a lesson taught by nature, was not lost, and it was thus that the mysterious method of germination upon the base of the mother plant was inaugurated. This strange and unintelligible technique was not published, so we can not honor its inventor. It evidently remained a trade secret which for a very long

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[1] There are regions in South America, notably in the district of Pacho, celebrated for the famous *Odontoglossum crispum*, where all the Indian population is employed in hunting for orchids, small villages furnishing hundreds of these hunters. This intense exploitation makes one fear the rapid disappearance of some of the beautiful species.

[2] It is certainly Neumann (chef des serres du Museum de Paris) in 1844 and Moore in Glasnevin (Dublin, Ireland). See Costantin, Les étapes d'une découverte biologique. Les hybrides d'Orchidées (Revue scientifique, 29 fevrier, 1913, 257).

time was unknown not only to the public, but even to the most skillful horticulturists.[1] There is every reason to believe, however, that it was in the Veitch houses at Chelsea that the methods were perfected which enabled Dominy, who was employed as a gardener in that great establishment, to dare undertake a work of long duration which was to produce wonderful results. I refer to orchid hybridization. The work of hybridization always occupies the attention of horticulturists whenever they introduce a new plant. It has been carried on with such great success for the begonias, pelargoniums, and chrysanthemums. If up to the middle of the nineteenth century they had not undertaken the task with orchids it was only because they were rendered powerless by their inability to secure germination; and horticultural activity, rendered fruitless, had to exercise itself in some other direction to satisfy the admirers of these beautiful plants. It was thus that the importations took the prodigious flight described above, and that the number of cultivated species came to be so enormous—from 2,000 to 6,000 in the whole family. Nowhere else in the vegetable kingdom is there another province where the exertion has been so prodigious from this point of view.

After 1850 we enter upon a new era, although at first the change was scarcely appreciable. Discoveries were kept concealed and their results made their appearance very slowly, so that it was not comprehended at first that horticultural evolution was engaged in new directions. Dominy, after he had been initiated by Dr. Harris into the very peculiar specializations presented by the sexual mechanism of the orchid flower, undertook the first cross-fertilizations. Moreover, he showed his gratitude much later, in 1869, when the first Cypripedium hybrid appeared, for he gave it the name of *Cypripedium Harrisianum*. This plant was a very important hybrid, but obtained at a comparatively late date. Long before, in October, 1856, *Calanthe✕Dominyi* had made its appearance. It was the result of crossing *Calanthe Masuca* with *Calanthe furcata*. The seeds were sown in 1853 and three years were sufficient for the appearance of a new plant, for it was indeed a new creation.

After these widely separated periods, 1856, the date of appearance of the first orchid hybrid, and 1869, the date of appearance of the first hybrid Cypripedium, an immense task was undertaken by horticulturists, and the number of their creations has been multiplying in a disquieting fashion. At the present time 600 hybrids have been obtained in the genus Cypripedium alone by crossing them with some 40 species of the Paphiopedilum found exclusively in tropical regions of the Old World. Moreover it may be stated that the

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[1] "A living plant is needed to render sanitary (?) the substratum in which germination is to take place." Bois, Dictionnaire d'Horticulture.

number 600 was obtained only by a statistical method which may be considered too restrictive, for it was employed by Mr. Rolfe with a view to simplifying a study rendered every day more difficult by new creations. He has adopted the strict rule of giving only a single name, the oldest, to all the crosses between any two species. But this rigid rule, which is quite practical for purposes of taxonomic study, takes no regard of the fact, which is nevertheless very important and well established, that the offspring obtained from the same parents at the same period or at successive periods are often very different, and especially that if an inverse crossing is made very dissimilar hybrids result. The Cypripediums being hermaphrodite, either of the species may be taken as father or as mother. If the rule of nomenclature just cited is not admitted, it is not 600 but 1.500 hybrids that must be listed for this single genus. One can understand how Lindley said, when *Calanthe* × *Dominyi* appeared, "You will drive botanists mad." Never until then had the words of Bailey been so true: "The garden has always been the bugbear of the botanist." It must be remembered that the artificial creations thus obtained among the orchids, and especially among the lady's-slippers, have characters which must be emphasized, which are different from those usually seen in chrysanthemums or roses. The immense number of varieties that are known as belonging to these two floral types differ from one another by peculiarities which are often infinitesimal, slight variations in tints, habit, etc. When examined as a whole in an exhibition there is an impression of continuity. It is seen, however, that by the accumulation of these slight differences extreme types altogether different are obtained. Upon inspection of the Cypripedium hybrids the impression is different; the plants that have been crossed with one another are so unlike—separated by so many diverse characters—that their offspring give the impression of autonomous beings which are radically different from anything before known and give one the idea of new beings created in every part, for whose analogue the whole world might be searched in vain. The hybrids thus fashioned by man's genius have every appearance of new species: and by the processes of cultivation and multiplication, which consist in dividing the rhizomes, once the being has been created by a stroke of a magic wand, we are assured of keeping it indefinitely with all the characters which have struck us at the time of their first appearance.

When one of these prodigies is offered in the salesrooms of the London auctioneers there is a contest among its fond admirers for the possession of a gem hitherto unknown, and it is not unusual to see new hybrids sold at absurd prices. For example, *Cypripedium Thalia* was sold for 300 pounds sterling ($1,500) and *Cypripedium*

Germaine Opoix, produced by the skillful chief gardener of the Luxembourg, was sold in London for 7,650 francs ($1,530)..

Such high prices are justified by the rarity of the plants, by the difficulty of producing them, and by their wonderful beauty. Sometimes it requires 20 years of effort and cultivation to succeed in germination, nurse the seedling with the closest attention, combat all the enemies that lie in wait for it, protect it from all the dangers that threaten it, and bring it to flower. But gradually these rareties are brought to light, and in a not far distant future the lovers of the Cypripediums, who hitherto have had only some 50 types to choose from, will have hundreds or even thousands. The hybrids have the very remarkable character, so to speak, of being indefinitely prolific, so that by crossing them among themselves their number can be increased almost without limit.

Each grower, in searching to create a new type, pursues an ideal which is sometimes realized in a happy fashion. Perfection is not obtained at the first stroke, but by successive improvements it is finally approximated. Among the most successful creations of M. Opoix, chief gardener of the Senate, may be mentioned the offspring of the Luxembourg Oenanthum, which was itself celebrated for the gigantic dimensions of its flowers. In spite of its incomparable qualities, this plant was not yet the phenomenon dreamed of by the insatiable hybridizer, so he searched for new blood to infuse into it. For this he turned to a handsome little Indian Cypripedium, from the region of Bhatan, the Fairrie Cypripedium, which had been introduced into Europe in 1855. This delicate species had been lost successively by all the horticulturists who were ignorant of the proper treatment to give it and the Luxembourg garden was the only establishment which had been able to keep it. From this instance of longevity it may be seen that an orchid well cared for may be kept almost indefinitely. By crossing this Cypripedium with the giant Oenanthum there were obtained two prodigies among the lady's-slippers, Germaine Opoix and Gaston Blutel, which surpass everything thus far obtained in the splendor of the amply spreading labellum and the warm coloring, characters manifestly inherited from *Fairrieanum.* The influence of the parents is displayed in these hybrids in a striking manner, as in an indefinite number of other types, and such authentication gives to this study a charm and a profound biological interest.

The number of new types may be increased, moreover, in the near future, in an extraordinary manner, thanks to a discovery of the greatest importance which is yet to be mentioned. Despite the wonderful results just cited, those who obtained them were ignorant until within the last few years of the true reasons for the cultural technique they employed. They knew this was the case from the numerous

failures they experienced. The yield of seeds is always irregular and uncertain. Very often, without any apparent cause, successful results are obtained in one greenhouse and complete failure in another. Finally, although hybridizations had given first-class results with Cypripediums, Cattleyas, and Laelias, there was a host of genera famed for the splendor of their flowers whose seeds could not be germinated. Such was the case with the Odontoglossums for a long time. It was indispensable to find an explanation of these anomalies.

The riddle is solved to-day and in such a thorough fashion that the consequent results for an industry of the first rank will be of the highest importance. It was known from the studies of Wahrlich, published in 1886, that the roots of orchids invariably contain fungi. The fact had been demonstrated long before by Schleiden von Ressek, Prillieux, and other botanists, but no one knew until Wahrlich made his investigations that it was a condition existing in 500 representatives taken at random in the orchid family, thus being a peculiarity nearly universally characteristic of the group. It seemed to me [1] that important consequences must result from this verification, and that the invasion of the roots of these plants by fungi must have affected their evolution and been the cause of their peculiarities of structure and modes of life. The statement, in particular, that in all the true holosaprophytes (plants without chlorophyll and bearing fungi in their roots) the seed was undifferentiated, led me to affirm that the minuteness of orchid seeds, so marked that they are described as scobiform, was one of the remote results of the presence of mycorhiza and due in all probability to toxins, which, acting at a distance, prevented the development and production by the embyro, as in nearly all seeds of a radicle, a hypocotyl, and cotyledons.

This new point of view involved unexpected results: the seed deprived of fungi must certainly be infected once it was placed in the soil and it might be surmised that the failures of horticulturists in their attempts to germinate seeds resulted from their ignorance of the peculiarities which have just been set forth concerning the biology of the plants. It was reserved for one of my students, Mons. Noël Bernard, to gain the credit for the proof that these deductions were quite correct. After having worked with the bird's-nest Neottia and tried vainly to germinate the microscopic seeds, he had the good fortune upon a botanical excursion to find a capsule of this plant which was bent toward the ground and had dehisced upon the soil. Its seeds had germinated. Upon studying their structure he saw that they were infected by a fungus, in all

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[1] Costantin, La nature tropicale (Bibliothèque scientifique internationale, p. 226), 1898.

probability the same as that upon the roots of the parent plant. This happy observation shed a ray of light; it explained all the failures in cultivation experienced by growers, as well as the reason for their success when they placed the seeds about the base of the mother plant.

However, a new method of cultivation which was gaining ground in the horticultural world seemed not to substantiate the preceding explanation. Instead of placing the seeds at the base of the mother plant some gardeners sowed them in earthenware saucers containing various substrata, such as sawdust. As they frequently obtained successful results they maintained that it could not be a question of infection by fungi from the roots, and the explanation given by Mons. Noël Bernard which so revolutionized the ideas of horticulturists seemed to them still less admissible, in view of the fact that their trials were always fruitless whenever a kind of white growth, some mold or fungus, invaded the sawdust amid the fine orchid seeds sown there. This unscientific objection was in vain, for on making sections of the embryos developed upon the sawdust it was found that they were always regularly infected by the fungus, which invariably entered in the same manner, by the micropyle (suspensor), and invaded the cells, producing there tightly rolled balls of threads. This irrefutable observation did not completely solve the question, for whence came the fungus in this case? This is still an unsettled point. The first hypothesis which occurs to one is that the fungus is so abundant in the greenhouse that it infects the sawdust naturally, like the mold in a cheese cellar, whose presence enables the manufacturer to obtain excellent products but whose absence brings him ruin. Perhaps there is a simpler explanation— that the gardener, naturally of a clever and often furtive disposition, has placed in the substratum fragments of roots which have thus infected the seeds with their fungi. The last explanation seems to me not at all improbable, because at the conclusion of Bernard's investigation Mons. Denis, an orchid grower of Midi, France, actually employed this method and obtained good results. When horticulturists thus employ subterfuges to deceive and throw off the track disinterested investigators who are trying to perfect their industry they make a mistake, for it is to their best interest to seek the intelligent aid of science, which can guide their work and be of the greatest assitance to them. It too often happens that they conceal mysteriously some trick of the trade, the reason for which they do not understand, although it brings them success and may even be the foundation of their fortune. It is easily imagined that they protect their secret with jealous care, but unhappily secrets can not be kept indefinitely.

One of the most skillful propagators of our country, Mons. Maron, after the publication of Mons. Bernard's investigations, said that he succeeded as well with his own method as with that recommended by the latter, this consisting in inoculating the soil with orchid fungi, which he had learned how to separate from the roots and grow in pure cultures. This statement does not seem to have great weight when it is stated that on sending some orchid fungi to an inexperienced amateur, who had never germinated a single orchid, like Mons. Magne, with whom I put Mons. Bernard in communication, wonderful success was obtained. The intervention of science will at least have had the advantage of rendering accessible to many a process which previously had been successfully attempted by only a few.

Besides, despite the mastery of their art obtained by certain worthy breeders, they still have disappointments, and failures frequently baffle the most experienced of them, fortune, on the contrary, often reserving her smiles for unskilled novices. As long as the reasons for the methods they employ are not understood this ought not to be surprising. The production of seed is always meager, and, above all, irregular. One capsule begins to develop; another not until several weeks or even months afterwards. There are a host of anomalies and failures in growth for which an explanation should be sought. Moreover, there is a convincing example which proves that the new methods of cultivation can be a powerful aid to the cultivator; this is the notable success obtained in the case of *Phalaenopsis Artemise*. Seeds of this hybrid, obtained by crossing *Phalaenopsis amabilis*, a variety of *Rimstediana*, with *Phalaenopsis rosea*, were sent by Mons. Denis to Mons. Bernard before the capsule which contained them had opened. The latter was able to remove the seeds aseptically and place them in a sterilized tube, where no germination took place. Upon introducing a pure culture of a fungus, *Rhizoctonia mucoroides*, there was obtained in the tube a splendid germination, the seedlings developing with the utmost rapidity and regularity, so that at the end of 18 months Mons. Bernard was able to remove the seedling and send it to Mons. Denis, who replanted it, and in 1908 (less than 3 years after sowing) the plant flowered.[1] It was the first mature plant obtained by the new method, grown with a rapidity that even the most skilled growers were unable to attain, for Mons. Bernard's seeding of 18 months had nearly the size of those 3 years old which are figured by the Messrs. Veitch in their excellent orchid manual.

So by extracting the fungi from the roots anyone can obtain as good and even more rapid germination than that secured by the most

[1] Orchid Review, vol. 17, p. 156.

expert growers. Besides, after knowing the reasons for the methods employed one may travel farther in the path of progress and attempt many germinations that no one has known how to secure until now. It can thus be foreseen that in the near future the growing of orchids will receive a new impetus while the number of successes in cultivation will continue to increase, and new hybrids will become more and more numerous. At the present time there are signs in the horticultural world, especially in England and Belgium, that all the recent discoveries have been appreciated; we hear of an unexpected number of new floral offerings which indicate that the daring of the growers is increasing daily. The flowers that are today the queens of fashion are the Odontoglossums. The creations obtained from the representatives of this genus are multiplied every day and the types like the Odontiodas (the result of a cross between an Odontoglossum and a Cochlioda) are the glory of the exhibitions. One would never suspect that a venerable science like botany, apparently adapted only for the delight of collectors who have a pleasant fancy for gluing dry plants on paper, could be capable of affording such assistance to an industry so important as that of orchid growing. It could not be anticipated that the biology of these plants was so extraordinary. They are, in short, plants that are normally diseased, which not only accommodate themselves to their parasites but are unable to exist without them. It may nevertheless happen that the latter take the offensive and then the plant is killed. The struggle must be continuous between the fungus and its host, and in certain cases it happens that the resistance of the orchid is so strong that the mycorhiza is completely digested and nothing remains at the end of this violently defensive act but some excreta or the débris of half atrophied threads. The reaction of the host under normal condition is always severe, and the phagocytose, which functions in a regular manner, limits every day the threatened progress of the parasite. It may be easily understood that such a struggle affects the whole structure of the plant and that the normal characters of orchids depend upon it to a large extent. The evolution of the attacking organisms is analogous to that of those attacked. The fungi separated from a Vanda are not the same as those found in an Odontoglossum; they are parasites of the same family, but distinct specifically. One is tempted to believe that for each orchid there is a corresponding fungus specifically different from all others. At present it appears that there is only a small number. Three species clearly distinct have been described;[1] one which inhabits the roots of Cypripediums, Cattleyas, and Laelias: another which is

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[1] Burgeff admits that in every orchid there is a different species of fungus (*Orcheomyces*). Burgeff. Die Wurzelpilze der Orchideen. Jhre Kultur und ihr Leben in der Pflanze. Jena. 1909.

associated with species of Phalaenopsis and Vanda; and a third restricted to the Odontoglossums. These fungi, ordinarily parasites, can be cultivated away from their usual host upon an artificial medium. It is then found that their threads have the property of rolling up upon themselves into a ball, so that under artificial conditions they conduct themselves in the same manner as in the cells of the host which they have invaded in the usual fashion. It seems probable that here one has to do with a property of acquired heredity which enables them to exist independently of the cause which has produced them.

When a Phalaenopsis is inoculated with the fungus from a Cypripedium, or an Odontoglossum with that of a Vanda, one may have, according to the case, a disease which is often of an infectious character, or wholly negative results. Very often the foreign fungus penetrates the seed, provokes the beginning of germination, then development is arrested; afterwards a new infection is produced which is this time fatal, and the plant dies. The parasite has regained its formidable destructive character, which was evidently its primitive condition. It may happen. on the contrary, that the fungus is defeated in the combat; it penetrates the seed, but is completely digested and germination does not take place. There is finally another case which is of special interest: This is when the parasite and the host are adapted to each other, and a new association is formed. If, as we have previously suggested. the orchid was partly created by the fungus, there is every reason to believe that this change will modify the germinative evolution, and abnormal types will be produced. In fact, such monstrosities have been secured with a Cymbidium, and more successfully with a Vanda. In the latter genus, in place of having a plant with a simple stem and of symmetrical growth, there was obtained a small body with two. three, four, or even nine branches. Mons. Bernard was able to grow some of these strange little plants for several months. He even sent some of them to horticulturists in hope that they might know how to continue their growth and bring them to flower. An unfortunate and vexatious accident interrupted the attempt. The mistake of a workman caused the destruction of the precious plants, and what might have been learned from them is still a secret. Still, if the ideas which we have expressed are correct, we do not hesitate to believe that if such a product had been brought to maturity, it must have given the most unexpected results. Horticulturists have known how to obtain extraordinary and very interesting types by hybridizing species with one another; but it is known that anomalies may be produced in the vegetable kingdom otherwise than by crossings. Mons. Blaringhem has shown that various forms of transmission, such as division, torsion, and compression, can direct evolution along new paths, and create characters previously

unknown which are often inheritable. The experiments of Mons. Bernard show us that by changing the fungi of orchids one may create monstrosities; that is to say, in short, transform the orchid. It may be that the change thus brought about will be so profound that the creatures thus formed may be unmanageable; but if they can be brought to flower and reproduced, in all probability there will be some very curious creations. It can be seen that breeders still have a vast field to exploit.

As a sequel to these remarks, some deductions may be drawn. At present too much attention is given to the study of hybrids. The Mendelian laws, so long forgotten, and recently brought to light again by the work of De Vries, Tschermak, Correns, and Bateson, would lead one to believe that the key to the riddle of evolution had been found. These laws, it must be stated, are applicable only to very simple cases, such as that of two varieties which differ from each other by one or a small number of characters. The characters of their offspring are then subject to indisputable mathematical laws. They do not seem applicable, at least at the present moment, to cases of two parent species of an offspring, differing from each other by numerous characters. If even these complex cases could be cleared up and reconciled with Mendelian principles, the result would be a theory that evolution takes place only in the ovule. Can we admit that an exterior influence can never cause the appearance of new characters? Upon this there can be no division of opinion. All that has been set forth above with regard to the orchids pleads a contrary case, which is in accordance with the theory set forth by Lamarck, the famous disciple of Buffon.

THE MANUFACTURE OF NITRATES FROM THE ATMOSPHERE.[1]

By Ernest Kilburn Scott,

A. M. Inst. C. E., M. I. E. E.

[With 3 plates.]

Considering that it is only about 10 years ago that the manufacture of nitrogenous products by electric power was proved to be commercially possible, the progress has been remarkable. Indeed, this metallurgical development of electric power promises to be even more important than electric traction.

The two main sources of fixed nitrogen are sulphate of ammonia from gas works, etc., and sodium nitrate from the country of Chile. Table I gives the sulphate of ammonia produced in this country in the years 1906, 1909, and 1910. It will be noticed that the principal increases between 1906 and 1910 are, from coke ovens, 115 per cent, and from producer-gas plants, 50 per cent; the total increase being at the rate of about 26 per cent.

TABLE I.—*Sulphate of ammonia.*

	1906	1909	1910
	Tons.	*Tons.*	*Tons.*
Gas works	157,160	164,276	167,820
Iron works	21,284	20,228	20,139
Shale works	48,534	57,048	59,113
Coke ovens	43,677	82,886	92,665
Producer-gas plants	18,736	24,705	27,850
Total	289,391	349,143	367,587

The regular exportation of nitrate of soda from Chile began in 1830, and, as will be seen from Table II, it has increased at an extremely rapid rate and is now about two and a half million tons per annum.

TABLE II.—*Exports of sodium nitrate from Chile.*

Years.	Tons per annum.	Years.	Tons per annum.
1830	935	1908	1,970,000
1850	50,000	1909	2,108,600
1870	222,000	1910	2,308,200
1890	1,050,000	1911	2,420,400
1907	1,600,000		

Against these figures the output of calcium nitrate and calcium cyanamide, which are two of the main products of the electric fixation of nitrogen processes, seems small. The important thing to notice, however, is that electrical processes are now on a sound commercial footing, and very large extensions of plant have been recently made, and are in hand.

Table III gives particulars of the installations for the manufacture of calcium nitrate by the *direct* process of Prof. Birkeland and Mr. Sam Eyde. It will be noticed that, although the first experimental plant was started only nine years ago, already the company controlling the Birkeland-Eyde patents have installations aggregating 200,000 horsepower at work, and probably by 1916 another 300,000 horsepower will be at work. All the installations mentioned in Table III are in Norway, but installations will no doubt be erected in other countries.

TABLE III.—*Installations of the Norwegian Hydroelectric Nitrogen Co.*

Year.	Horsepower.	Name of installation.
1903	25	Experimental plant at Frognerkilens.
1903	160	Experimental plant at Ankerlökken.
1904	660	Arendal.
1905	45,000	First Notodden (Svaelgfos).
1910	15,000	Second Notodden (Lienfos).
1912	140,000	First Rjukan installation.
1913	120,000	Second Rjukan installation.
1914	70,000	Vamma.
1915	80,000	Matre.
1916	70,000	Tyin.

The other electrically produced nitrogenous manure, calcium cyanamide, is made by a more *indirect* method invented by Dr. Franck and Dr. Caro, and its manufacture is not confined to Norway.

Table IV gives the principal installations, and it is of interest to note that, although the first one on a commercial scale was erected at Piano d'Orto in Italy only 8 years ago, there are works in operation and being built which by the end of next year will be making calcium cyanamide at the rate of over a quarter of a million tons per annum.

The Nitrogen Fertilizers Co., which owns the Odda & Alby Works, works under license from the North-Western Cyanamide Co., which company controls this country, Norway and Sweden, Belgium, and all the British colonies, protectorates, and dependencies, except Egypt and Canada. The Odda factory is now being enlarged and at the beginning of next year will be producing 73,000 tons per annum.

In the United States, the American Cyanamide Co. is about to erect a works in Alabama to manufacture 24,000 tons per annum.

BIRKELAND-EYDE FURNACE.

This furnace, invented by Prof. Birkeland and Mr. Sam Eyde, of Norway, depends on the inter-action of an alternating-current arc in a constant magnetic field. The furnace, as installed at Notodden, consists of a circular sheet-steel drum about 8 feet in diameter and 2 feet wide, lined with refractory fire-brick, and having a disklike space in the center $6\frac{1}{2}$ feet diameter and $1\frac{1}{4}$ inches wide. Air is supplied at the center of the furnace by a Root's blower, whilst a channel round the periphery of the disk space carries off the gases and unoxidized air, as shown in figure 1.
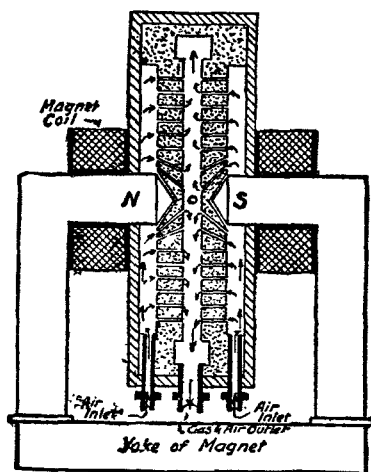
FIG. 1.

TABLE IV.—*Installations for manufacture of calcium cyanamide by the Franck and Caro process.*

Name of company.	Place of installation.	Output per annum in tons.
Nitrogen Fertilizers Co. (North-Western Cyanamide Co.)	Odda, Norway	15,000
Do.	Alby, Sweden	15,000
Società Italiana de Prodotti Azotate	Piano d'Orto, Italy	4,000
Società ̈̈̈̈̈̈	Terni, Italy	15,000
Società	San Marcel, Italy	3,000
Société	Martigny, Switzerland	7,500
Do.	Notre Dame de Briancon	7,500
Bayerische Stickstoff Werke	Trostberg, Bavaria	15,000
Ost-Deutscher Stickstoffcalf und Chemische Werke	Bromberg, Prussia	2,500
A. G. Stickstoffdunger	Knapsack, Germany	18,000
Società per l'Utilizzazione della Forze Idrauliche della Dalmazia.	Selenico, Dalmatia	4,000
Do.	Dugirat, near Almissa	80,000
Japanese Nitrogen Products Co	Kinzei, near Osaka	4,000
American Cyanamide Co	Nashville, Tenn	4,000
Do.	Niagara	12,000

Two electrodes, one of which is shown in figure 2, project into the center of the furnace and are approached to within about one-third

FIG. 2.

inch. They are copper tubes, $1\frac{1}{2}$ inches diameter and five-eighths inch thick, and have water circulation to keep them cool.
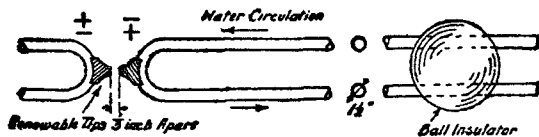
Surrounding the points of the electrodes there is a magnetic field of about 4,500 lines of force per square centimeter. Alternating current at 5,000 volts and 50 periods per second is supplied to the electrodes, and direct current flows around the coils to produce the magnetic field.

When an arc is struck between the electrodes it is at once deflected in a direction perpendicular to the lines of force, and the necessity of having alternating current applied to the electrodes will be appreciated from the fact that with direct current the arc would be deflected to one side only. As each electrode is alternatively positive and negative, the arc is projected outward first to one side and then to the other, thus giving a disk of flame about 6 feet in diameter. The speed at which the arc moves outward is extremely rapid, and as the formation of a new arc is practically instantaneous, it appears to the eye as a sheet of flame.

When the extremities of the arc retire along the electrodes the arc increases in length, its resistance also increasing, until the tension is such that a new arc strikes between the points of the electrodes. The resistance of this short arc being smaller, the tension of the electrodes suddenly sinks to a point that will not sustain the long arc, which is thus extinguished. Another arc starts, and so the process goes on.

An inductive resistance is a very necessary piece of apparatus to have in series with the arc, because its self-induction automatically effects a displacement of phase according to the currents flowing, thus enabling the arc to burn steadily.

The writer assisted Mr. Howles with some experiments in fixation by nitrogen about 13 years ago, and it was then that the necessity of having an induction coil in circuit was noted. Without it the arc could not be maintained steady, but with it the arc was quite steady. The experiment was made at Messrs. Johnson and Phillips's, Old Charlton, and a transformer that happened to be handy was used for the purpose.

It should be noted that any furnace working with alternating current has necessarily a considerable phase difference. In other words, the power factor is low, and therefore, in estimating the sizes of dynamos and cables, due allowance has to be made. This, of course, raises the cost of electric energy. For ordinary power supply a power factor of 0.85 is quite usual, but with fixation of nitrogen furnaces the power factor is only about 0.6.

A curious feature of the arc flame is that it is not quite concentric. When looked at through colored glasses the extremities of the arc appear like glowing spots upon the sides of the electrodes; on the positive electrode they are small and fairly close together, whilst on the negative electrode they are larger and farther apart. The reason for these spots appears to be that the arcs solder themselves, so to speak, to the electrodes, and the magnetic lines of force make the extremities of the arcs move along in leaps. For some reason not yet explained, the extremities of the arc cling more closely to the negative than to the positive electrode, and therefore the flame extends farther

along the positive electrode than along the negative, as shown in figure 3.

When the flame is burning it emits a loud noise, from which the furnace attendant can judge of the number of arcs formed per second. The electrodes are changed and repaired every 300 hours, and the fireproof lining every fourth to sixth
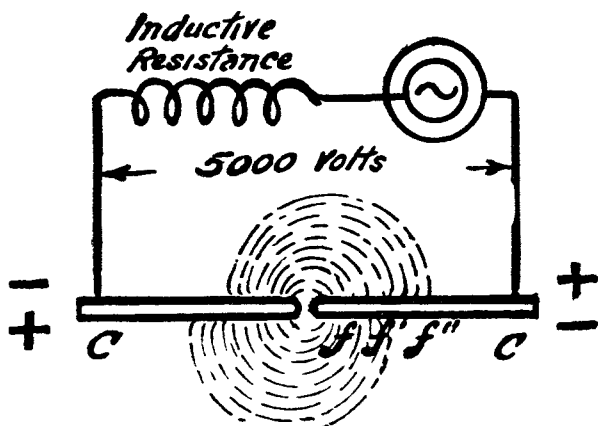
FIG. 3.

month. The temperature of the flame is about 3,500° C., and the temperature of the escaping gases is between 800° and 1,000°.

Each of the furnaces at Notodden takes 600 kilowatts, and the furnaces at the Rjukan works each take 3,000 kilowatts.

SCHONHERR FURNACE.

FIG. 4.

This furnace was invented by Dr. Schonherr, of the Badische Anilin und Soda Fabrik of Germany. As installed at Christiansand, it consists of a long iron tube fixed vertically, through the center of which an arc 16 feet long is maintained. Alternating current at 4,200 volts, 50 periods, is used, and each furnace takes 600 horsepower. Air blown through this tube with a whirling motion keeps the arc in the center. The electrode at the bottom consists of an iron rod which passes through a copper water-cooled tube. The iron rod is pushed upwards, as it burns away to ferric oxide, and fresh rods are screwed on as required, so that the process does not stop. At the top of the tube there is a water cooler, and it is inside here that the arc ends by striking across from the center to the side of the tube.
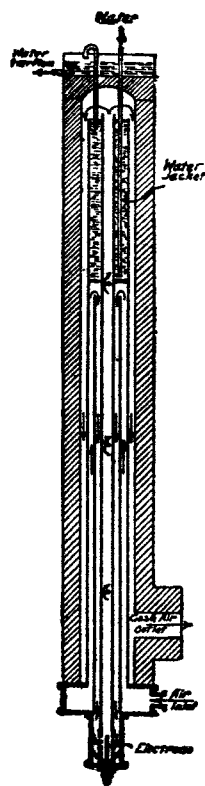
As will be seen from the arrows in figure 4, the incoming air passes through annular tubes, on each side of which there are the hot gases from the furnace. The air is thus heated to about 500° C. before it reaches the arc. After passing through the arc, where some of it

is heated to about 3,000° C., it reaches the water cooler, where its temperature is then suddenly reduced. At this point there is a rapid mixing of the highly heated nitric oxide next to the arc, with the cooler air that is whirling past, and the gas becomes permanently fixed. The nitric oxide and air leave the top of the cooler at about 1,200° C., and pass away to a gas flue, common to all the furnaces, where the temperature is reduced to about 850° C.

The plant at Christiansand is entirely occupied in making sodium nitrite for the production of aniline dyes, etc. Previously sodium nitrite had been made by the reduction of Chile nitrate with lead, but this method of production has now practically ceased.

The nitrite made from the nitrogen of the air is so satisfactory and so cheap, compared with the old methods, that now practically the whole supply of the world, valued at £160,000 ($800,000), is obtained by electricity.

In order to produce it the temperature of the gases is not allowed to fall below 300° C., and this keeps the nitric oxide about equal to the nitrogen peroxide. This mixture behaves as if it were nitrogen trioxide N_2O_3, and it is absorbed completely by being brought into contact with sodium hydroxide according to the following formula—

$$NO+NO_2+2NaOH=H_2O+2NaNO \text{ (sodium nitrite)}.$$
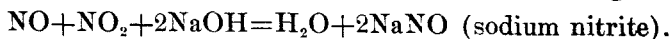
CALCIUM NITRATE.

As carried out at Notodden, the method of making calcium nitrate is as follows: The nitric oxide gas and air pass from each furnace into two fireproof-lined gas-collecting pipes, about 6 feet in diameter, lined with fire brick. These pipes convey the gas to four steam boilers, the heat given off by the gases being used to raise steam for concentrating the products and for driving the air compressors for pumping acids, soda, etc. The gases then go through tubes in the evaporating tanks, after which the temperature is down to about 250° C. The temperature is lowered still further, to 50° C., by passing it through a number of aluminium tubes over which cold water is flowing. The gas then enters the oxidation tanks, which are large vertical iron cylinders, having acid-proof linings. Here it continues to take up oxygen to form nitrogen peroxide, the percentages being now about 98 per cent air and 2 per cent nitrogen peroxide.

The nitrogen peroxide is brought into contact with water to form nitric acid, in two series of four towers. These towers are built of granite and are filled with broken quartz, this substance and the granite being chosen because they are not affected by acids. Each tower measures 2 meters square by 10 meters high, and it has been found that they will give an absorption of 3.3 kilograms of nitric acid per cubic meter of space per 24 hours.

The liquid trickles down through the quartz, and meeting the nitrogen peroxide gas, combines with it. The liquid moves from tower to tower in the opposite direction to the gas. Thus the fresh water enters at top of the fourth tower, it flows down through the interstices between the pieces of quartz and falls into a granite tank. From there it is pumped by compressed air to the top of the third tower, down which it trickles into another tank, and from which it is pumped to the top of the second tower, and so on.

When the liquid reaches the bottom of the first tower it contains about 40 per cent nitric acid.

Recently some very remarkable results have been obtained by improving the material with which these towers are filled. By using special forms of earthenware instead of quartz, the towers can be reduced in size considerably, and as the cost of the towers is usually about four times the cost of the filling material: this means much cheaper towers.

The chemical equations are as follows:

In the electric furnace from 3.000° C. down to 1.000° C., nitric oxide, a colorless gas, is formed—

$$N_2 + O_2 = 2NO \text{ (nitric oxide)}.$$
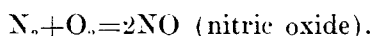
In the oxidation chambers, etc., from 500° C. down to 50° C., the red-brown gas nitrogen peroxide is formed—

$$2NO + O_2 = 2NO_2 \text{ (nitrogen peroxide)}.$$
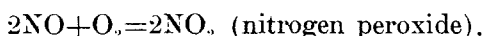
In the four acid absorption towers the nitrogen peroxide combines with water to form nitric acid and nitrous acid—

$$2NO_2 + H_2O = HNO + HNO_2 \text{ (nitrous acid)}.$$
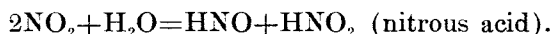
As the nitrous acid is unstable in an aqueous solution it gives nitric acid and nitric oxide—

$$3HNO_2 + H_2O = HNO_3 + 2NO \text{ (nitric oxide)}.$$
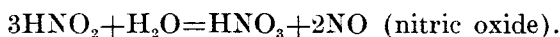
The nitric oxide then combines with more oxygen to form again nitrogen peroxide, and the above equations are repeated—

$$2NO + O_2 = 2NO_2 \text{ (nitrogen peroxide)}.$$
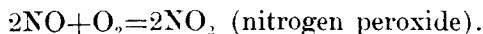
What is left of the nitrogen peroxide and nitric oxide gases pass to the fifth tower, when they meet sodium hydroxide to form sodium nitrite—

$$NO_2 + NO + 2NaOH = H_2O + 2NaNO \text{ (sodium nitrite)}.$$
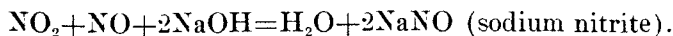
The nitric acid of 40 per cent solution is sprayed onto calcium carbonate, and the carbon dioxide gas is driven off, leaving calcium nitrate—

$$2HNO_3 + CaCO_3 = CO_2 + H_2O + Ca(NO_3)_2.$$
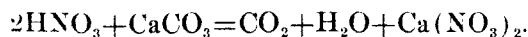
The solution is then pumped into solidification pans, under which cold air is circulated to accelerate cooling, and the nitrate of lime stiffens into a brittle, crystalline mass. This is broken up into lumps, which pass to ball crushing mills, where it is reduced to a granular state. The coarse powder is then raised by an elevator into a hopper, from the bottom of which it falls into barrels which hold 2 hundredweight. These barrels are lined with paper to guard against damp. The analysis of the commercial calcium nitrate, Norwegian saltpeter, or nitrate of lime as it is variously called, is given in Table V.

TABLE V.

Element.	Symbol.	Per cent.	Element.	Symbol.	Per cent.
Calcium oxide	CaO	25.83	Magnesium oxide	MgO	0.41
Nitrogen	N	12.47	Aluminium trioxide	Al_2O_3	0.71
Water	H_2O	23.83	Residue insoluble in hydro-		
Carbon dioxide	CO_2	0.52	chloric acid		0.51

With the Birkeland-Eyde process, 1 kilowatt-year gives 500 to 550 kilograms of nitric acid, or 853 to 938 kilograms of nitrate of lime. The latter usually contains 13 per cent of nitrogen, which corresponds to 111 to 122 kilograms of combined nitrogen. It is guaranteed to contain $12\frac{3}{4}$ per cent of nitrogen.

The best result at Notodden has been 900 kilograms of nitric acid per kilowatt-year measured at the arc terminals and allowing for 100 per cent nitric acid.

The percentages of nitrogen and comparative prices of the various artificial manures are about as given in Table VI.

TABLE VI.

	Content of nitrogen.	Price per ton.		
	Per cent.	£.	s.	d.
S...l...........sworks	19.75	13	0	0
Nitrate o'......: : : (.	15.50	9	15	0
N'l.... el i:.... ..i. ricity	12.75	8	10	0
Calcium cyanamide made by electricity	18.00	10	0	0

THEORY OF FIXATION.

The problem is to raise the temperature as quickly as possible to over the igniting point of nitrogen and oxygen and then immediately to cool the fixed gas and draw it off. The temperature of the burning nitrogen and oxygen flame is lower than the igniting point by about 200° C. There must be a "hot-cold zone"—that is to say, a zone in which at one part the temperature is enormously high, and at another part the temperature is as low as possible.

As the electric arc gives in an easy manner the temperature above ignition point it is principally used. Some experimenters contend, however, that if by using a flame of carbon monoxide or a sprayed oil flame of carbohydrates a temperature near that of the electric arc was reached, then the results would be equally satisfactory. They point out that the ignition of nitrogen and oxygen takes places at 1,800° C., and as the temperature of the electric arc is well over 2,000° C., it is really much lighter than is necessary.

It is not at all certain, however, that the effect is merely due to temperature. A more probable theory is that some of the oxygen is first formed into ozone and that farther on in the arc the extra atom of oxygen splits off, and being in a nascent condition readily combines with the nitrogen. In this connection it is interesting to note that Sir. J. J. Thompson has demonstrated that under certain conditions N_3 does exist. Is it possible that O_3 and N_3 are first formed and then the nascent atoms combine?

It is known that nitric acid is formed on the windings of high-tension alternators and this is apparently due to silent discharge at normal temperature and pressure.

Mr. Cramp, whose investigations into this subject deserve to be better known, says. in a communication to the writer, that he is quite certain that ozone does enter into the problem, and that if the air charged into the furnace had ozone mixed with it, there would be an increased yield of fixed gas. A very small amount of ozone is likely to have a considerable effect; 12 parts in 1,000,000 is a high percentage. In the Central London Railway tube the percentage is only 1 part in 1,000,000, and yet the ozone is so powerful that its characteristic odor is quite noticeable.

The photograph (pl. 1) shows that with alternating current the arc concentrates on one side, and the fact that ozone is a conductor may be partly or wholly responsible for this.

On several occasions it has been suggested that the yield would be higher if nitrogen and oxygen were passed through the furnace in combining proportions instead of in proportions in which they exist in air. Muthman says, however, that the proper proportions are one of nitrogen to two of oxygen, and his explanation is that as NO_2 is easiest to form it is, therefore, formed first.

Several methods of fixing nitrogen have been proposed which do not depend on electric power. The principal one is due to Prof. Haber, and it is of special interest just now, because the powerful German company, the Badische Anilin und Soda Fabrik. is experimenting with it.

The gases nitrogen and hydrogen in the proportions for forming into ammonia are brought together under a pressure of 175 atmospheres, and they are said .to combine in the presence of a catalyser, such as osmium or uranium.

THE RJUKANFOS INSTALLATION.

The Rjukan installation is situated in Vestfjorddalen, East Telemarken. The saltpeter factories are situated at Saaheim and the hydroelectric power plant on the Maane River, half a kilometer away. The power installation, utilizes part of the well-known " Rjukanfos," and has a working head of some 274 meters and a discharge of water of 47 cubic meters per second. The total electrical energy in the power station is about 140,000 horsepower, divided into 10 units, each of 14,450 horsepower. Each unit is, however, capable of producing 16,500 horsepower, and they are thus the largest hydroelectric units which have yet been constructed. The generators give a pressure of 10,000 volts, and the total energy is transferred to the nitrate of lime factory through a transmission line, for the most part made of bare aluminium conductors.

In the factory some of the furnaces are of the Schonherr construction (of the Badische Anilin und Soda Fabrik), each of 1,000 kilowatts. They are 23 feet long and require 40,000 cubic feet of air per hour. The other furnaces are of Birkeland-Eyde's construction, each of 3,000 kilowatts. (See pl. 2.)

The gases from the various furnaces have a temperature of about 800° C. when leaving, and they are led through brick-lined iron pipes to the coolers, which are mounted in a separate house. From there the gas goes to the absorption towers. These towers are arranged on the same system as at Notodden, namely, acid absorption for the greater part of the gases and alkali ones for the rest.

The annual production will amount to 70,000 tons of nitrate of lime and 8,000 tons of nitrite. It will be exported in wooden kegs, exactly as at Notodden.

Regarding the question of the type of furnace, Mr. Eyde wrote on February 10 last, saying:

The results now at hand from the trial management are not sufficient to entitle us to judge which of the two systems—the Badische or the Birkeland-Eyde system—is the more profitable one. For the present it may be declared that the proceeds by both systems very likely will turn out to be approximately the same. As you will note, however, from the above-mentioned figures, the Birkeland-Eyde furnaces may be constructed for a considerably greater energy than the other type.

A second power plant is now under construction at Rjukan, intended for the installation of some 120,000 horsepower, which will likewise be used for the manufacture of nitrate of lime.

Our company is further constructing a third power installation, Vamma, on the Glommen River, by which will be produced 70,000 horsepower, of which 50,000 horsepower will be utilized for the manufacture of nitrate of lime. Including the factory at Notodden, we will thus in a short time utilize in all 370,000 horsepower for the manufacture of nitrate of lime.

PLATE 1.

ARC FLAME SHOWING CONCENTRATION ON ONE ELECTRODE WHEN WORKING WITH
ALTERNATE CURRENT.

PLATE 2.
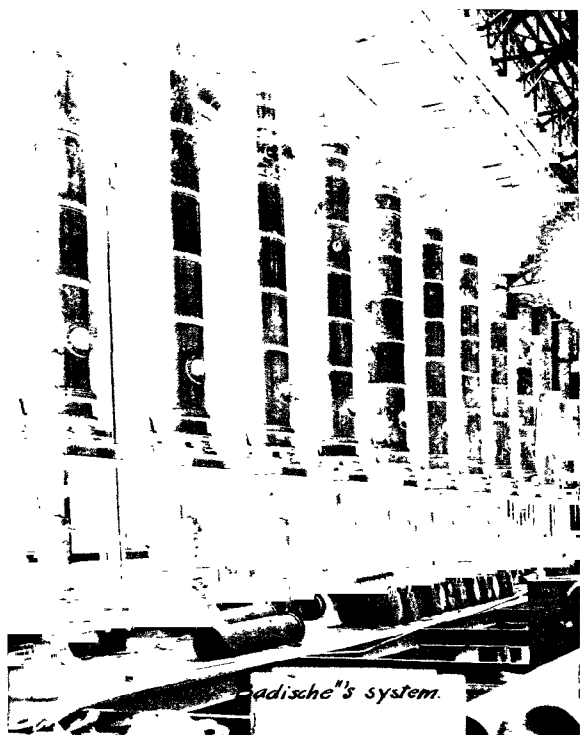
FIG. 1.—RJUKAN SALTPETER FACTORY.

View of furnace room showing some of the Schonherr furnaces.
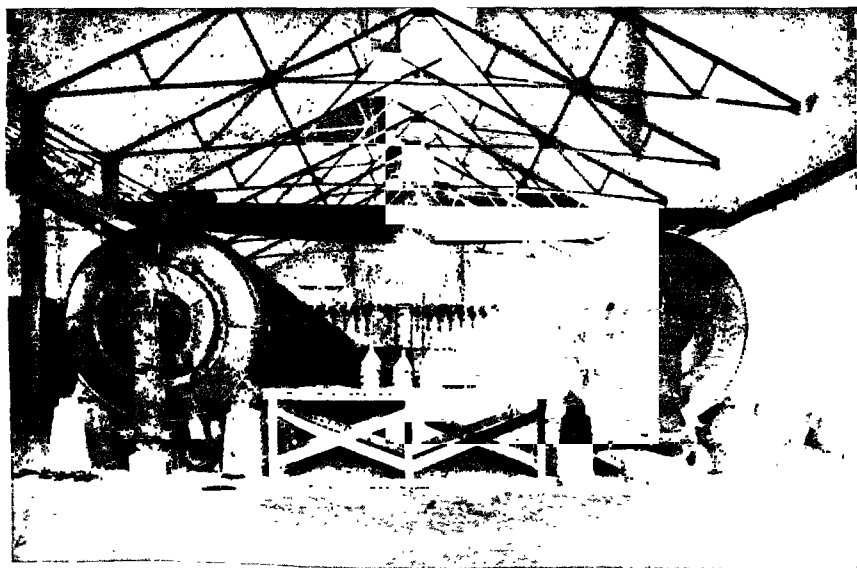
FIG. 2.—RJUKAN SALTPETER FACTORY.

View of furnace room showing twelve of the Birkeland-Eyde furnaces.

It would appear that the Birkeland-Eyde furnace is preferred to the Schonherr, because it is more compact and cheaper to build. The Schonherr furnace has to be built very high in order to increase its output, and this introduces constructional difficulties; also the difficulty of keeping the arc from striking into the side of the tube.

The present plant consists of 10 generator turbines of 14,450 horsepower each, 5 of which were constructed by J. M. Voith, of Heidenheim, 5 by Escher Wyss & Co., of Zurich, and 1 exciter turbine of 1,000 horsepower by Kräerner Brug, of Christiania. The 3-phase electrical generators coupled to the Voith turbines were made by the Allmänna Svenska, of Västeras, Sweden, and those driven by the Escher Wyss turbines were supplied by Brown, Boveri & Co., of Baden. The whole of the switchboard equipment was installed by the Westinghouse Co.

The turbines are fed by individual pipe lines of 1,250 millimeters inside diameter at the top end and 1,000 millimeters inside diameter at the bottom end. The length of each pipe is 720 meters (2,360 feet); the upper 300 meters consist of riveted pipes, and the longer lower part for higher pressure consists of welded pipes. The riveted pipes were supplied by Frederikstad's mek. Verksted, Frederikstad, Norway, and the welded pipes by Actiengesellschaft Ferrum, Zawodzie near Kattowitz, Germany. The supply and laying out of all of the pressure pipe lines was done under the superintendence and on the responsibility of J. M. Voith.

Each turbine is designed to work with a net head of 274 meters, and a normal output of 13,000 horsepower, when running at a speed of 250 revolutions per minute. The output may be increased to 14,450 horsepower.

The main sluice valve of 1,000 millimeters is fitted on a taper connecting pipe and the valve is operated by hydraulic pressure by means of a cylinder with piston and a distributing valve. The piston rod carries a relay which connects it to the valve, thus preventing the latter opening or closing too quickly and insuring perfect safety. The distributing piston is designed and dimensioned to allow the valve being opened or closed under full pressure. This valve is provided, however, with a by-pass valve 150 millimeters inside diameter.

The turbines are provided with twin Pelton wheels, each of which is driven by two nozzles. In the Escher Wyss turbine the lower jet does not strike the buckets until the latter have cleared the upper jet. Each of the runner wheels, which are mounted 1,800 millimeters apart on a horizontal steel shaft, consists of a separate hub of cast steel, and on the circumference of each 22 cast-steel buckets are fastened. The buckets are held by means of two rings, which pro-

vide that there shall not be any stress on the bolts, and yet prevent the buckets getting loose.

Bearings.—The turbine shaft, which is of Siemens Martin steel, is supported by two ring-lubricated bearings of 380 millimeters diameter, and its diameter is increased to 470 and 480 millimeters where the runner wheels are mounted. A forged-on flange coupling transmits the whole power of the turbine to the generator shaft. In addition to lubricating rings, each bearing is provided with a separate pump for the circulation of the oil, and this pump is driven by the turbine shaft. It draws the warm oil from the bearings, passes it through a coil situated in the discharge pit of the turbine, and then pumps the oil through a filter to the main shaft again. This device greatly increases the safe running. The bearings have to withstand the weight of the shaft and runners, and also the thrust due to the water jets. They are supported by a strong frame, which is grouted into the foundations and held fast by anchor bolts.

Casing.—On the same side as the distributing pipe there is a strong frontal iron plate, to which the inlet bend and distributing piping are fastened. The upper half of the casing is made of wrought iron 10 millimeters thick, in two parts bolted to the foundation frame and to the frontal plate at the center line. When the runner wheel has to be taken out for repairs the upper part of the casing is lifted off. At the side of the casing where the shaft comes through it, deflector rings and water-splash guards prevent any water escaping from the casing. For the purpose of inspecting the buckets and nozzles a pit is provided in the foundations by means of which it is possible to descend into the turbine chamber for that purpose.

The turbine-chamber walls are covered with iron plates from the foundation frame up to the ceiling of the tailrace, with a view to protect them from erosion as well as to prevent any leakages in the air ducts between the turbines.

Nozzles.—The largest diameter of the water jet when the nozzle is fully opened is about 150 millimeters. In order to reduce the regulating power the needle rod is provided with a balancing piston acting in opposite direction to two buffer springs. The latter have, the tendency to close the needle. The power resulting from the closing energy of the needle and springs and the opening energy of the piston is so calculated that the needle is always balanced, no matter what the opening is. The turbine is regulated by simultaneously adjusting the four nozzles, which are connected to each other by means of rods and levers. A rod and lever connects the regulating shaft to the main shaft of the universal oil-pressure governor.

Guarantees.—For the speed governor and pressure regulator, as well as for the efficiency of the turbines, the following guarantees

were given. The turbines were designed to develop a maximum of 14,450 horsepower when working with a net head of 274 meters and running at 250 revolutions per minute. The efficiency was to be 76 per cent when the quantity of water used was 5,200 liters per second. When running under the same conditions of speed and pressure and developing normally 13,000 horsepower, the efficiency was to be 78 per cent and the water used 4,650 liters per second. When load was suddenly thrown off to the extent of 25, 50, and 100 per cent, the variations of speed were to be limited to 3.5 per cent, 7 per cent, and 17 per cent above normal and the maximum increase of pressure in the pipe line was not to exceed 15 per cent.

All these guarantees were easily maintained. In May, 1911, the pipe lines were filled and the turbine started for the first time. A number of tests were then carried out, and about three months later the definite taking-over tests of all the turbines were made by Mr. Geheimrat Reichel, professor of the Charlottenburg Technical School of Berlin. The output of the turbines was measured by electrical means; the quantity of water used was measured by the "Schirm methode" in the tailrace. The highest efficiency that was attained was 82.6 per cent, with an effective turbine output of 11,000 horsepower. With nozzles fully opened the maximum effective horsepower of the turbines was about 16,000.

The maximum increase of speed was 15 per cent, whilst the increase of pressure above static head did not exceed 10 per cent.

The five Escher Wyss turbines are each coupled to 3-phase generators, made by Brown, Boveri & Co., of Baden.

At a power factor of 0.6 each machine gives 17,000 kva. at 11,000 volts, 50 periods per second. One of the machines gives the whole of the 17,000 kva.

Four of the units are of the double generator type, with a shaft common to the two. The two armatures are separated by a fireproof partition, so that if a coil of one should be burnt out the coils on the other machine are not affected.

Allowing for windage and friction, the guaranteed efficiency is 94.8 per cent for the double generator and 95.3 per cent for the single generator. This is at full load and with a power factor of 0.6.

The voltage difference from full load to no load and vice versa is 1,400 volts. This may be necessary by the conditions of working the furnaces, as they are very subject to sudden changes.

The total weight of one generator is 205,000 kilograms (200 tons). Ninety-two thousand kilograms go to the rotating field and shaft. The armature weighs about 90,000 kilograms.

The armature stampings are held in position in the cast-iron armature ring by vee grooves. Cast-iron rings clamp the stampings at the ends and these rings extend to bottom of slots. The outside

diameter of the armature is 6 meters and the inside diameter is 4.4 meters. The radial depth of the laminated structure is 21.5 centimeters. To permit of overhaul and repair the armature is divided on its horizontal diameter.

The magnet wheel has a cast-steel hub and arms, and the periphery of the wheel is made up of solid forged steel rings. To these rings cast-steel poles are fixed, the ends of the poles being laminated. The poles are held by dovetails and cotters.

The field poles are wound with bare annealed copper on edge and all the pole windings are in series.

The slip rings are of cast steel and carbon brushes are used. The exciter is direct coupled and gives 130 kilowatts at 220 volts.

Every rotor was tested for mechanical strength by being rotated at 1.8 times the normal speed for half an hour; that is, at 450 revolutions per minute.

The bearings are supplied with oil under pressure and the oil is cooled by water coils.

The other five turbines supplied by J. M. Voith are very similar to the above, with double-runner wheels and two nozzles to each runner. At the official tests all the guarantees were exceeded. Coupled to each of the Voith turbines is a double 8,400 kva., 11,000 volts, 50-cycle, three-phase generators made by the Allmänna Svenska Co. Each consists of two seperate armatures and two revolving fields on a common shaft running on two bearings. By reason of the highly inductive load on the generators, the PF is only 0.6, but with PF=unity, each machine would develop up to an individual capacity of 23,000 electrical horsepower. Each double generator weighs 250 tons.

Figures 1 and 2, plate 3, are from photographs of some of the plant used in the Rjukanfos power house.

PAULING FURNACE.

This furnace was invented by Mr. H. Pauling, of Gelsenkirchen, Westphalia, and he took the idea from the well-known horn-break lightning arrester. As installed at Gelsenkirchen and Innsbruck it consists of two hollow iron electrodes, arranged to form a vee, which at the lowest point is about 4 centimeters across, as shown in figure 5. At this point there are two lighting knives, which can be approached to within a few millimeters and are readily adjustable. The arc strikes across and runs up the diverging electrodes by reason of the natural convection currents, and the repelling action of its own magnetic field, but principally because of a blast of heated air from an air-duct immediately below. The arc diverges as it follows the shape of the electrodes, and it attains a length of about

PLATE 3.
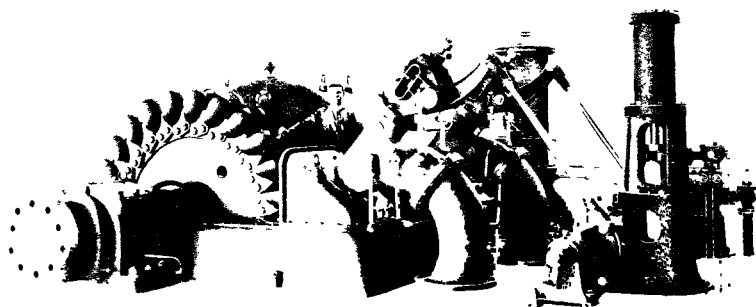
FIG 1.—RJUKAN POWER HOUSE.

Fifteen thousand horse power, Voith double turbine, running at 250 revolutions per minute.
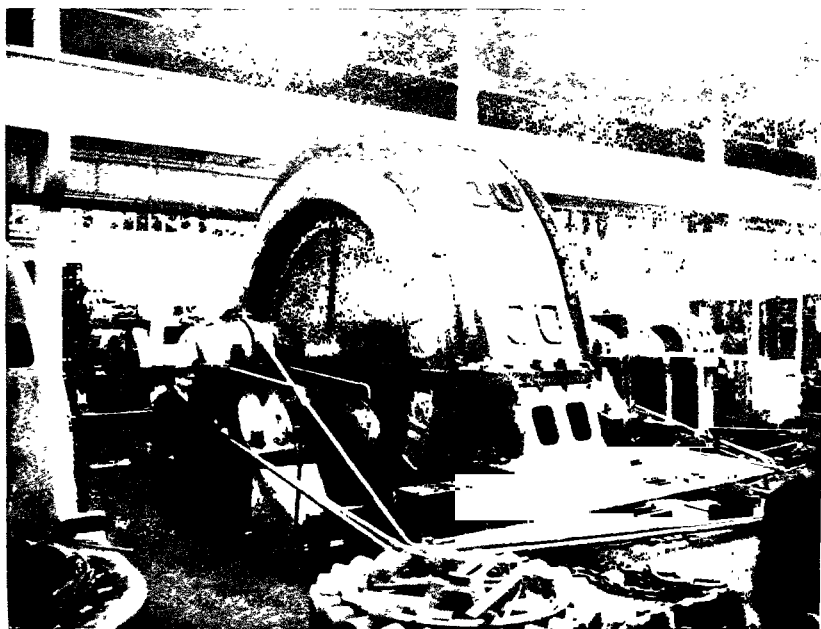
FIG. 2.—RJUKAN POWER HOUSE

One of the 8,100 Kva, three-phase alternators made by the Allmanna svenska Electric Co.

a yard. At each half-period of the alternating current a fresh arc forms, so that the result is the equivalent of a triangular sheet of flame.

An important feature is that the wall which divides the two parts of the furnace is hollow, and gas and air which has been through the furnace previously and been cooled is blown through this central passage. As will be noticed from figure 5, this cool gas and air strikes into the top of the arc flame, and it serves to cool the gases which have just been formed. The two arcs are in series, and the furnaces work in sets of three—one to each phase. Each furnace, therefore, receives single-phase current at 6,000 volts, 50 periods per second.

At Gelsenkirchen there are 24 such furnaces, each taking 400 kilowatts at 4,000 volts.

FIG. 5.

The arcs are started by means of copper starting knives, which can be approached to within a few millimeters at the bottom, when the two horns come together. When the arc has been started, these starting knives are withdrawn, and the larger space between the electrodes is then sufficient to let the hot air from the tuyère pass through freely. The starting knives last 20 hours, whereas the main electrodes, which are of steel and water cooled, last 200 hours.

The works of La Nitrogène Cie, at La Roche-de-Rame, Hautes Alpes, France, have nine Pauling horn-arrester furnaces of 600 horsepower each in operation, and nine more, of 1,000 horsepower each, are being added.

The general layout of the plant is shown in figure 6, and it will be noted that the furnaces are arranged in sets of three—one furnace to each phase.

The fresh air for the furnaces is supplied by a 250-horsepower turbo-compressor, running at 3,000 revolutions, and before it gets to the furnace tuyères it passes through a preheater. The air travels through the furnace at 1,200 feet per second.

When the gases come from the furnaces their temperature is about 1,000° C., and the nitric-oxide content 1.15 to 1.5 per cent. They first pass through the preheater, and give up some of their heat to the fresh air going to the furnaces.
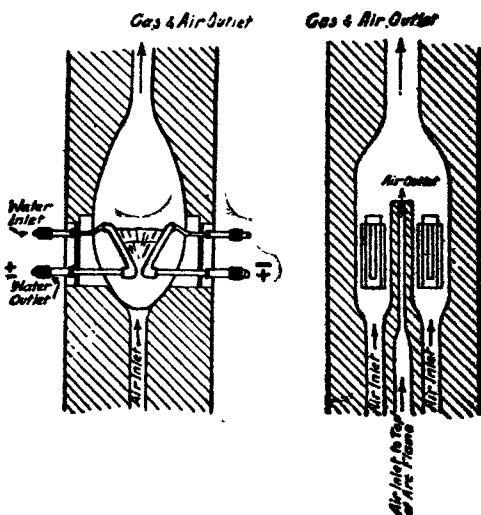
The gases then pass through the two cooling towers, which are outside the furnace house. Each of these towers is 16 feet in diameter and 40 feet high, and filled with fire brick. When the bricks of one tower have become hot the gases are switched over to the other tower. Fresh air is then drawn through the heated tower by means of the chimney (85 feet high), and the brickwork in it is thus cooled.

The gases are sucked out of the cooling tower by a 15-horsepower fan and forced into the oxidation tower, which is built of reinforced concrete and measures 33 feet diameter and 75 feet high. Here, the temperature having fallen to 600° C., oxidation to NO_2 goes on rapidly.

From the oxidation tower there are two pipe lines, and one takes some fixed gas and air back to the furnaces, where it is passed through the central passage and comes in contact with the freshly fixed nitrogen at the top of the arcs. In this way the fresh gas is cooled without being diluted.

FIG. 6.—THE LAY-OUT OF THE WORKS BY LA NITROGÈNE CIE, FRANCE.

A second pipe line, of aluminium, takes the remainder of the gases to the absorption towers, each of which contains 250 tons of stoneware packings. The gases pass from 1 to 5, whilst the water, gradually accumulating more and more acid, flows in the opposite direction, namely, 5 to 1. Montejus operated by compressed air raise the solution to the top of the different towers.

The concentration of acid at bottom of No. 5 tower is about 5° Beaume; at bottom of No. 4 it is 8°; at bottom of No. 3 it is 15°; at bottom of No. 2 it is 25°; and at bottom of No. 1 it is 35°, which corresponds to about 40 per cent of HNO_3.

The gases from No. 5 absorption tower still contain a small amount of NO and NO_2. They are passed through an acid filter, in which the last traces of acid are condensed, and then pass to the nitrite towers. These contain sodium-carbonate solution, and the gases react with it to form sodium nitrite, having a concentration of 20 per cent. This is submitted to evaporation, the hot furnace gases being used for the purpose, and white sodium-nitrite crystals are obtained containing 95 per cent of nitrite and 3 per cent of nitrate.

The nitric acid goes to the acid concentrators, in which it passes through a series of porcelain and fused quartz vessels arranged in

stairway fashion. The acid is also heated by direct contact with hot gases which come from the furnace. These gases are thus charged with water and nitric-acid vapor.

To condense the acid the gases are passed through a cooling coil of stoneware, which offers a large cooling surface. The remainder of the gases then pass to the oxidation tower and mix with those coming from the furnace.

The acid obtained by the process is 36° Beaume and contains 50 per cent HNO_3. The concentration can not go beyond 60 per cent by this process, because the vapor produced has a concentration which increases with the concentration of the solution, and for 66 per cent the vapor produced has exactly the composition of the liquid.

To obtain higher concentration other processes must be resorted to, and as high as 98 per cent can be obtained.

Some idea of the efficiency of the plant may be obtained from the fact that Mr. Pauling guarantees 60 grams of 100 per cent HNO_3 per kilowatt-hour of electrical energy, measured at the entrance of the electric transmission line into the factory; and also that the electrochemical plant proper will cost about 120 francs (£5) per kilowatt.

The Southern Electro-Chemical Co., of Nitrolee, S. C., in the United States, has a 4.000-horsepower plant on the Pauling system for manufacture of calcium nitrate. Electric energy is generated in two water-power plants at Great Forks and Rocky Creek.

CALCIUM CYANAMIDE.

The discovery of calcium cyanamide came about as the result of a research by Dr. Franck and Dr. Caro, who were following on the lines of some previous work of Playfair and Bunsen. Their immediate object was to make cyanide of potassium for the recovery of gold from tailings, and they incidentally found that barium carbide absorbed nitrogen to form barium cyanamide. By using calcium carbide they obtained a similar reaction, according to the formula—

$$CaC_2+2N=CaCN_2+C$$
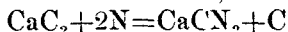
It was then found that by treating calcium cyanamide with hot water it gave off ammonia according to the equation—

$$CaCN_2+3H_2O=CaCo_3+2(NH_3),$$
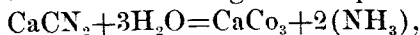
and this gave rise to the idea of using it as a manure.

As carried out at the Odda Works the calcium carbide broken into lumps is delivered to crushing machines, from which it passes to mills in which it is ground fine, the whole of these operations being effected automatically in an air-tight plant so as to prevent acetylene gas being given off. It is of interest to note that the glowing mass from the calcium carbide furnace can not be used straight away.

The powder is then filled into electric furnaces, of which, in the first installation at Odda, there are 196, each holding 300 kg.

Figure 7 is a rough sketch of the furnace, and it will be noticed that down the center there is a cardboard tube to provide a space for the carbon pencil. After the carbide has been filled in the carbon pencil is fixed in position and the lid fastened down and made airtight.

Alternating current is now switched on and the temperature is raised to 800° to 1,000° C. The cardboard tube and certain cardboard partitions which had been placed in the furnace when the calcium carbide was run in are burnt up, and they leave spaces which allow the nitrogen gas, which is admitted under pressure, to circulate freely. Electric current is kept on for 25 hours, and at the end of 35 hours all the nitrogen has been absorbed, as shown by the meter.

FIG. 7.—ELECTRIC FURNACE FOR MAKING CALCIUM CYANAMIDE.

At Odda this nitrogen is made by the Linde distillation process, but in one of the French factories the Claude process is used.

The 196 furnaces make about 30 tons of calcium cyanamide, containing 18 per cent of nitrogen, per day of 24 hours.

When it is turned out of the furnace the cyanamide looks like black clinker. After being broken up it is fed into jaw crushers and then goes to roulette mills, where it is ground up fine for market.

It is then packed in a paper-lined bag, which is in a jute bag. For tropical countries there are two outer jute bags.

Recently improvements have been introduced at the Odda Works whereby, with the same amount of power and labor, the output has been increased from 12,000 tons to 15,000 tons per annum.

The furnaces are now being made to hold 450 kg., instead of 300 kg. Another improvement is that the cyanamide is treated with enough atomized water to reduce free carbide to less than one-half of 1 per cent.

From the point of view of engineers in this country, the installation of A. G. Stickstoffdunger at Knapsack in Germany (see Table

IV) is perhaps the most interesting. Gas is generated from cheap brown coal and used in gas engines to generate the electric current.

Although calcium cyanamide is mostly employed as a manure, it has other uses. For example, by treating with superheated steam very pure sulphate of ammonia is obtained. Also ammonium nitrate and dicyandiamide are made from it.

EXPLOSIVES.

Although manures form the main outlet for the products of these electric fixation of nitrogen processes, there are other important uses.

At the Notodden saltpeter factory ammonium nitrate is made by bringing the nitric acid into contact with ammonia liquor from our English gas works. The ammonia nitrate crystallizes out, and when dry it contains 35 per cent of nitrogen, and it sells in this country at about £27 a ton. It is the principal constituent of many of the explosives for mines.

Dicyandiamide, $C_2N_4H_4$, which is made by treating calcium cyanamide with water, when it crystallizes into broad needles or prisms is being used for mixing with explosives. It contains 66 per cent of inert nitrogen, and is used for lowering the temperature of the explosion.

This is of importance, because ordnance powders rapidly destroy rifling in guns on account of the high temperature. The importance of this is shown by the statement made publicly in 1905 that the 12-inch gun Mark VIII used on 15 British battleships could not stand more than 50 rounds full charge.

Nitric acid is, of course, the main constituent of guncotton, dynamite, and smokeless powders, etc., and at the present time we are mainly dependent on over-seas supplies of raw material from which to make the acid. In case of war we should undoubtedly be in a very serious position, for whereas most continental countries have plants for the fixation of nitrogen from the air, this country does not make a single ounce.

It will be remembered that at the time of the Napoleonic wars the French had difficulty in obtaining saltpeter with which to make powder; it behooves us, therefore, not to be caught in the same predicament. A few rounds from a broadside of modern guns blows away into the air as much nitrogen as was used during the whole course of a war of the last century. The necessity of having factories where explosives can be made to any amount, and quite independently of raw materials from overseas, is therefore obvious. Even if the product could not at first compete in price with existing supplies, the fact that it was a necessary addition to our national assurance against war

would justify the establishment of a works to fix the nitrogen of the air.

Various Government factories for the supply of munitions of war do not pay, from a strictly competitive point of view, yet everyone recognizes that they must be kept up.

COST OF POWER.

It will be of interest to consider briefly what are the prospects as regards the manufacture of nitrogenous products in this country. The problem is, of course, mainly one of cheap power, but to make it worth while there must also be a large supply because some of the furnaces take 1,000 kilowatts and upward.

In Scotland there are several water powers waiting to be harnessed, and one has been investigated which will give 10,000 kilowatts for a capital expenditure in hydraulic works and electrical plant of £200,000, or £20 per kilowatt installed. It is estimated that electrical energy could be turned out for 35s. per kilowatt-year, after allowing 10 per cent for interest and depreciation. The power is capable of extension.

In Norway electric energy is actually sold at about 20s. a kilowatt-year, or $\frac{20 \times 12}{8760} = 0.0275$ per kilowatt-hour, from which it would appear that the cost of installation is about £10 per kilowatt of plant, and a considerably lower rate than 10 per cent is allowed for interest and depreciation. Of course the carriage of the products from Norway to this country is an item, but it would not be much more than the carriage from Scotland to the south of England.

We know that very large steam-power stations with turbo-generators can be built for about £10 a kilowatt of plant, because the last extensions at Manchester cost only £12 per kilowatt, as shown by Mr. Pearce's (the chief engineer) figures.

	Per kw. installed.
Generating machinery. turbine condenser, alternator, etc	£3. 75
Boilers, economizers, superheaters, steam pipes, coal and ash conveyors, foundations, etc	2. 25
Switch gear for generators and feeders	. 55
Buildings with accessories	5. 05
	12. 05

In "Heavy Electrical Engineering," Mr. H. M. Hobart, after carefully considering all the details of a typical steam-power station, comes to the conclusion that "The complete cost of a station well designed on modern lines for an output of over 100,000,000 kilowatt-hours per year need not exceed £10 per kilowatt." With steam turbo-

generating units of 25,000 kilowatts, which are now being made, there is no reason why the cost per kilowatt should not come down as low as for Norwegian hydroelectric plants. Further, if instead of burning the coal in boilers it is made into gas and by-products are recovered, it seems likely that we shall be able to generate electricity as cheaply as the average for Norway.

To show what can be done by a producer-gas power plant, the following estimate by Mr. Chorlton, of Messrs. Mather & Platt, is of interest:

Producer-gas engine power station for 3,000 brake horsepower.

Capital costs:

Four 1,000 brake horsepower gas engines complete; coupled to four electric generators starting air compressor; gas, air, water, and exhaust pipes; and water pumps	£21,850
Buildings, engine foundations, crane, and silencer	2,770
Exhaust heat boilers	1,600
Switchboard and wiring	1,500
Water tank and cooling tower	400
Capital cost	28,120

This is equal to £7.03 per brake horsepower, or £10.545 per kilowatt.

Running costs, on the basis of 300 twenty-four-hour working days per annum:

Oil, waste, and stores	650
Repairs, rates and taxes, maintenance, insurance, etc., at 0.01d. per brake horsepower hour	900
Wages—Three shifts of one man at 40s. Three shifts of one man at 35s.	585
Interest and depreciation at 10 per cent	2,812
Total running cost per annum	4,947

Assuming the interest and depreciation to be only 6¼ per cent, the total running cost is — 3,892

The capital cost of a Mond producer plant capable of giving gas for 3,000 brake horsepower is — 13,200

The running cost of a Mond producer-gas plant is:

9,600 tons of shale	Nil.
900 tons of belt pickings	Nil.
1,500 tons of waste slack, at 4s. per ton	300
600 tons of washed slack, at 8s. per ton	240
Maintenance, including rates, taxes, labor (including packing), steam power, repairs, stores, etc., at 2s. 6d. per ton	1,500
Sulphuric acid, at 35s. per ton	665
Interest and depreciation, at 10 per cent	1,320
Running cost per annum	4,025

The by-products would sell for—

Ammonia sulphate, at £12 per ton_____ £4, 560
Tar, 15s. per ton_____ 180
Value of gas not included.

_____

Credit per annum_____ 4, 740
Leaving a net profit of £4,740 less £4,025=£715 per annum.
The net cost of energy, assuming interest and depreciation on station at 10 per cent, is £4,947 less £715=£4,232.
This is equal to 0.047 per brake horsepower hour, or 0.070 per kilowatt-hour.
The net cost of energy, assuming interest and depreciation on station at 6¼ per cent, is £3,892 less £715=£3,177.
This is equal to 0.035 per brake horsepower hour, or 0.052 per kilowatt-hour.

This 0.052 is for 300 days of 24 hours, but for the full number of hours in a year it becomes 0.043d. per kilowatt-hour, or 31s. per kilowatt-year. If this can be done with 1,000-horsepower gas engines, then there is considerable hope for the future when the internal combustion prime mover is made in as large sizes and as cheaply as steam turbines.

At the present moment, so far as fuel power stations are concerned, the position appears to be as follows:

For large prime movers of, say, 6,000 kilowatts and over the steam turbine is in an unassailable position. It is true that the large gas engine has been made in units of several thousand horsepower, but on account of its slow speed and its cycle of operations the size for a given power is very large as compared with a steam turbine. Its weight and price are greater, and the cost of foundations and housing accommodation very much greater.

The gas turbine, or the gas plus steam turbine, would solve the space difficulty, but although much has been written on the theory, and some work has been done experimentally, this form of prime mover is still in the air.

As regards the production of steam and of gas for the above-mentioned prime movers, it must be admitted that the method of burning coal on fire grates is less efficient than making gas from the coal and recovering the ammonia, etc. Also it is necessary to admit that there are mechanical limitations to the sizes of ordinary steam boilers as at present constructed.

On the other hand, gas producer and engine plants can not yet be considered altogether satisfactory, because the gas is so variable in quality. When steam is generated there is no doubt about the product.

With gas, on the other hand, there is no absolute certainty as to what its quality will be. It depends on the coal, on the condition of the apparatus, on the attention given by the workmen. If attempts are made to increase the yield of the ammonia, then the gas is likely to be poor, and if the gas is of good quality, then the by-products are apt to fall off.

A slight change in the kind of coal, and the whole of the gas apparatus has to be readjusted, and in the meantime the gas engines may have dropped to half power. On the other hand, with a steam boiler a change in the quality of the coal makes very little difference. The steam coming away is always of the same quality, however much the fuel may vary.

The Johannesburg fiasco is still fresh in our minds, but before that there had been similar troubles in large gas-power installations in Spain and elsewhere. As compared with the steam boiler, the large gas producer is still a faulty piece of apparatus, although it is being improved. On the other hand, the present type of boiler is not above criticism, for in size it has not kept pace with the steam-turbine prime mover. For example, at the Lot's Road power house there are eight boilers for each of the 6,000-kilowatt steam-turbo generators, and the cubic space occupied by the boilers is about five times that occupied by the steam-turbine set.

In the near future, steam-turbo generators will be of 20,000 kilowatts and over—one of larger size than that is now under construction by Parsons & Co.—and as the size of the prime mover increases, this space difficulty of the boilers also increases. It is absurd that one turbo generator should require a dozen or so boilers to supply it with steam.

A solution of the problem is the manufacture of the coal into gas with the recovery of sulphate of ammonia, tar, and oils. Then the gas must be burned in much more efficient boilers than those at present in use.

Hitherto gas-fired boilers have been of very low efficiency, say, somewhere about 50 per cent. but with the new method of Prof. Bone and Mr. C. D. McCourt an efficiency of over 90 per cent is attainable. The experimental plants at Leeds and at the Skininygrove Iron Works have demonstrated this beyond a doubt.

The method depends primarily on mixing gas and air together in the exact proportions for complete combustion, then forcing the mixture under pressure through tubes which are packed with pieces of refractory material. The mixture is fired at the outlet end of the tubes and strikes back to the entrance end. The flame quickly raises the refractory material to an intense heat, and complete combustion of the mixture takes place in about the first 6 inches from point of entry. The combustion having been completed, the remainder of the material acts as a baffle toward the burned gases as they traverse the tubes at high velocity, causing them to impinge repeatedly on the walls of the tubes. The evaporation is so rapid that the scaling troubles met with in other types of multitubular boilers are completely obviated, the scale being automatically shed in thin films about one-thirtieth inch thick as rapidly as it is formed.

The core of the material is maintained at a high temperature, but when it comes in contact with the walls of the tube it is so rapidly

cooled by the transmission of heat to the water that it only attains red heat.

A boiler erected on this principle at the Skininygrove Iron Works, Yorkshire, in November last, had the following dimensions: Ten feet diameter and 4 feet from back to front, 110 tubes, of 3 inches internal diameter packed with fragments of fire brick. The gas supplied from Otto Hilgenstock coke ovens is mixed with little more than its correct proportion of air, and the mixture is forced into the tubes at about 2 inches water-gauge pressure. The evaporation is 5,500 pounds of water per hour, and before being taken over by the Skininygrove Iron Works Co., it was run for a month day and night.

When one considers that a well-known boiler to evaporate 3,140 pounds of water per hour occupies about 23 by 13 by 15 feet, it will be seen how great a saving there is in space.

On February 21, 1912, Mr. Ernest Bury, M. Sc., wrote that the—

Boncourt boiler which was started up on November 7 last has continued to work very satisfactorily; its working is almost entirely automatic, and is included in the routine work of the exhaust-engine men, who have 11 running machines under their control.

The boiler has been off for inspection of the tubes, which proved to be clean and free from scale, a fact which I attribute to highly rapid ebullition. During the length of time the boiler has been at work we have had no trouble with priming, at all times the steam having been perfectly dry.

The average temperature of the waste gases leaving the plant has been 78–80° C., which is ample proof of the boiler's efficiency.

Generally, I consider that the boiler has come up to expectations. It is certainly the cheapest method of raising steam which has yet been devised.

SIR WILLIAM RAMSAY'S PROPOSAL.

The proposal to burn the coal in situ and bring the gases to the surface, when the ammonia, etc., can be extracted and the gases utilized for power, has attracted a good deal of attention.

That the coal when fired will keep alight for years and give off useful gases is quite well known. In New South Wales there is a seam of coal which has been alight for many years, but it is near the surface, and the air can get down fairly easily. With the deep seams of this country special provision would have to be made.

For burning out seams in old collieries the scheme is very attractive, because shafts already exist, and there are many seams which are too thin to work in the ordinary way. The limit for economical working appears to be 12 to 15 inches. Lidgett Colliery, near Barnsley, worked an 18-inch thick seam for many years, but it closed this year. There are, however, several other collieries in Yorkshire working seams in the neighborhood of 15 inches thick; one colliery near Wakefield having a seam 16 inches thick. In these very thin seams the men have to go along the gate roads laid on low trucks, face downward, and they propel themselves forward with their toes. It really is surprising that men can be found to under-

take such work, and no doubt, as time goes on, it will become more and more difficult to get men for this work. Of course, these very thin seams can only be worked when the coal is of very good quality and prices are good. We may take it, therefore, that Sir William Ramsay's suggestion has plenty of scope in the seams of under 15 inches thick, of which there are many.

There are also many pits which contain the particular coal known as "cannel," which is specially suitable for making gas. A case in point is the Leen Valley coal field of Nottinghamshire, where the seam known as "tophard" will be worked out in 20 years. Now, the top part of this seam consists of inferior cannel coal, and since the gas companies took to producing low illuminating gas and enriching it with other materials than cannel, practically none of it has been raised to the surface.

In the five collieries of the Leen Valley, namely Hucknall, Lenby, Annesley, Bestwood, and Newstead, there are millions of tons of cannel coal, to say nothing of slack left from the seam of tophard coal and a great deal of timber.

The shafts are already down and roads made, and supposing that lower seams prove unremunerative, then all this cannel coal could be burnt out for a supply of gas. There are certainly 15,000 acres of such coal within 120 miles of London.

EQUALIZING THE LOAD.

The problem of utilizing the electric energy of power stations at periods when such stations are working on low loads is beginning to attract the attention it deserves. The ideal for any power house is to secure a load of 100 per cent load factor, and there is no doubt that if greater efforts were made in this direction the price of power would come down considerably.

The valleys have been filled in, to some extent, by power and traction loads, but as these also have to be supplied at the same time as lighting the result was not as beneficial as it was thought it would be.

Now an electrochemical or metallurgical proposition is quite different, because such plants can often be shut down during the 24 hours for an hour or two; the load can therefore be adjusted to just fill up the valleys.

The Yorkshire Electric Power Co. was early in the field with this method of working, in connection with the carbide of calcium plant at Thornhill. It is of interest to note, by the way, that this power company is supplying electric energy to 15 collieries.

At Legnano a nitric acid plant of 4,000 kilowatts has been at work for some time past, which operates only during the night and certain hours of the day, when power is supplied at a cheap rate from the hydroelectric station by the Società Lombarda per Distribuzione dell' Energia Elettrica. Current is supplied by the power company at 50,000 volts, and, although the price charged does not transpire, it is

evidently at a figure that enables the process to pay, because an extension of 9,000 kilowatts is being installed.

A proposal that is being seriously considered at the present time in India is the utilization of the water power from an irrigation dam for the manufacture of manure. Owing to irrigation requirements, electric energy will only be available for nine months in the year, but that will not militate against the manufacture, as nitrogen fixation furnaces can be shut down and started up again at any time. The use of water from irrigation dams to manufacture manures for the farmers gives double benefit, and there are many places in the colonies. and in Australia in particular, where such a scheme is feasible.

The Indian scheme is for 30,000 horsepower, and it is said that 37,000 tons of calcium cyanamide, containing 18 to 20 per cent nitrogen. can be produced in the nine months with that power.

CONCLUSION.

We, as a nation, are sadly behind Continental countries in the exploitation of the electrometallurgical field. It is all very well to start manufacturing " when the business has steadied down," but generally by that time the best has been taken out of it. The processes become ringed round with patent rights, for naturally the master patents go to those who first commence to exploit a process commercially.

In the fixation of nitrogen nearly all the pioneer work of the laboratory stage was done in this country by Dr. Priestly, Lord Rayleigh, Sir William Crookes, McDougall and Howles, etc. The actual exploitation on a commercial scale has, however. been effected by a few Norwegian and German engineers, and the center of gravity of electrical enterprise at the present time appears to be in Scandinavia.

It is high time for the engineers and business men of this country to go into the matter to see why it is we are lagging behind, and especially to look into the question of cheap power supply. Above everything else, a progressive industrial country wants cheap power, whilst at the same time conserving its resources. We have carried municipal trading in electricity further than other countries, but have very little to show for it. There are a number of municipal plants run by committees of amateurs who know nothing about the business, and who frequently have not the sense to pay decent salaries to engineers who could tell them. What chance have such plants of generating cheaply?

The big things of electrical engineering are now being passed over because we lack cheap power, and this is especially the case in electrometallurgy. Within the next generation or so all previous work in electricity will look small against it. for the future is certainly for the electrochemist and electrometallurgist.

THE GEOLOGIC HISTORY OF CHINA AND ITS IN-FLUENCE UPON THE CHINESE PEOPLE.[1]

By Prof. ELIOT BLACKWELDER,

University of Wisconsin.

[With 9 plates.]

The Chinese Empire includes an area larger than the United States with the addition of Alaska and our insular possessions. A large part of this vast area, however, is made up of dependencies which are but loosely joined to China proper. and are not essential to its integrity. She has lost and regained these dependencies from time to time in the past. and the same process may continue. The accompanying map will serve to show the relation of these component parts of the Empire to each other and to surrounding countries.

Divested of its outlying possessions, China consists of 18 Provinces, which may be compared in a general way to our States. The Provinces are, however, generally larger than the States and, on the whole, much more populous. There is still greater dissimilarity in government because, whereas our States are representative democracies, the Chinese Provinces were, at least until within a year or two, satrapies ruled absolutely by imperial governors or viceroys.

Not a few people in America picture China as a vast fertile plain, perhaps like the upper Mississippi Valley, densely populated and intensively cultivated. In fact, however, it is so generally mountainous that less than one-tenth of its surface is even moderately flat. On the west, especially, it is ribbed with cordilleras from which its two great rivers, the Yangtze and the Hwang, flow eastward to the Pacific.

In addition to this diversity of surface, there is also much variety of climate. In the northwest the conditions are dry and severe, like those of Montana and central Wyoming, while in the southeast they are humid and subtropical, approaching those of the Philippine Islands. Such are the extremes.

It is a fact well known to geologists that continents, and therefore countries, have not always existed in their present state, but that they have been built as a result of successive events and changes of conditions. If we were to dig beneath the surface in any part of China, we should find first one stratum and then another, and we should see also that these strata have been bent, cracked, and otherwise disturbed. Some of these structures are old and some young. It would be somewhat like excavating in an ancient city, where one house or temple has been built upon the ruins of its predecessor, and each affords a crude record of its time. The geologic structure of such a country as China has been determined largely by the rocks of which it consists, partly by the climate to which it has been subject, but chiefly by the geologic events which have occurred during its history. Of course the beginnings of that history are unknown, just as the human history of China shades into darkness when we attempt to trace it back into the remote ages. But the present features of the land are chiefly due to the later events in its life, and these have been partly worked out by the geologists who have explored its surface.

FIG. 1.—SKETCH MAP OF CHINA.
Showing its outlying dependencies and its relation to other countries.

We may take as a convenient starting point for our interpretation a time far back in geologic chronology,[1] when China was a land surface which had been exposed to erosion so long that nearly all the hills and mountains that may have existed there before had been worn away, leaving a relatively flat plain, with groups of low hills here and there. The rocks beneath this plain were of various kinds, most of them highly folded. Eventually this surface was submerged beneath a comparatively shallow inland sea; and although the uneasy movements of the earth's body caused the sea bottom to emerge occasionally, it remained below the water nearly all through the geologic periods which constitute the Paleozoic era. By the end of that time

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[1] Just before the Cambrian period.

PLATE 1.

RELIEF MAP OF CHINA PROPER, SHOWING THE RELATIONS OF PLAINS TO MOUNTAINS

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we may picture China as a shallow sea bottom rising very gradually to a marshy coastal plain on the east. During the long intervening ages the accumulation of sediments upon the sea bottom had formed successive layers of limestone, shale, and sandstone, which eventually reached a thickness of 5,000–10,000 feet.

This condition did not hold without end, for eventually [1] strong compressive forces engendered in the underlying body of the earth squeezed the superficial rocks into folds, and thus bulged the surface high above sea level in the region so affected. By the prompt attack of streams, winds, glaciers, and the other agencies which are incessantly sculpturing the surface of the earth, these elevated districts were, even while rising, carved into rugged mountains and deep valleys, so that the original folds were greatly disfigured, even before the compressive forces ceased to operate.

It is a fact generally recognized among geologists that in terms of geologic time such episodes of compression and folding are short lived. They are soon followed by much longer periods, during which the internal forces of the earth are quiescent but in which the erosive agencies have free play. If any land remains indefinitely above sea level and is not disturbed by movements from below, the mountains and hills will eventually be worn away and there will be left only a broad, almost featureless, plain. It is believed that China, in consequence of such a period of quiescence,[2] was reduced to a lowland from which almost all of the preexisting mountains had been removed. In this condition it probably remained for more than one geologic period, and the western part may even have been submerged beneath the sea which at that time covered northern India and part of Tibet. In that sea were deposited the thick beds of limestone which are now found in some of the western mountain ridges.

Again, in the Miocene period the forces of distortion within the earth accumulated to such strength that they were able to repeat the mashing and folding, but this time the area affected lay farther to the west and south. At the same time, or perhaps earlier, the eastern part of China was cracked in various directions; and the intervening blocks, settling somewhat unevenly upon their bases, left a group of escarpments and depressions comparable to those now to be found in western Nevada and southern Oregon. As before, the work of erosion and the leveling of the surface was at once accelerated, so that even before the deformation had spent itself the blocks were deeply scarred. It is uncertain how far this period of erosion succeeded in reducing China to base level. The consummation may have been prevented by gentle warpings of the surface, rising very slowly here and sinking there. When compared with the great breadth of the

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[1] Jurassic period.   [2] Cretaceous and Eocene periods.

areas affected, these changes of level seem very slight, but they are nevertheless sufficient to cause great changes in the aspect of the country.

It is one of the basal principles of physiography that streams tend to produce in their channels an almost uniform slope from their headwaters to the sea. If any part of the channel is so flat that the stream
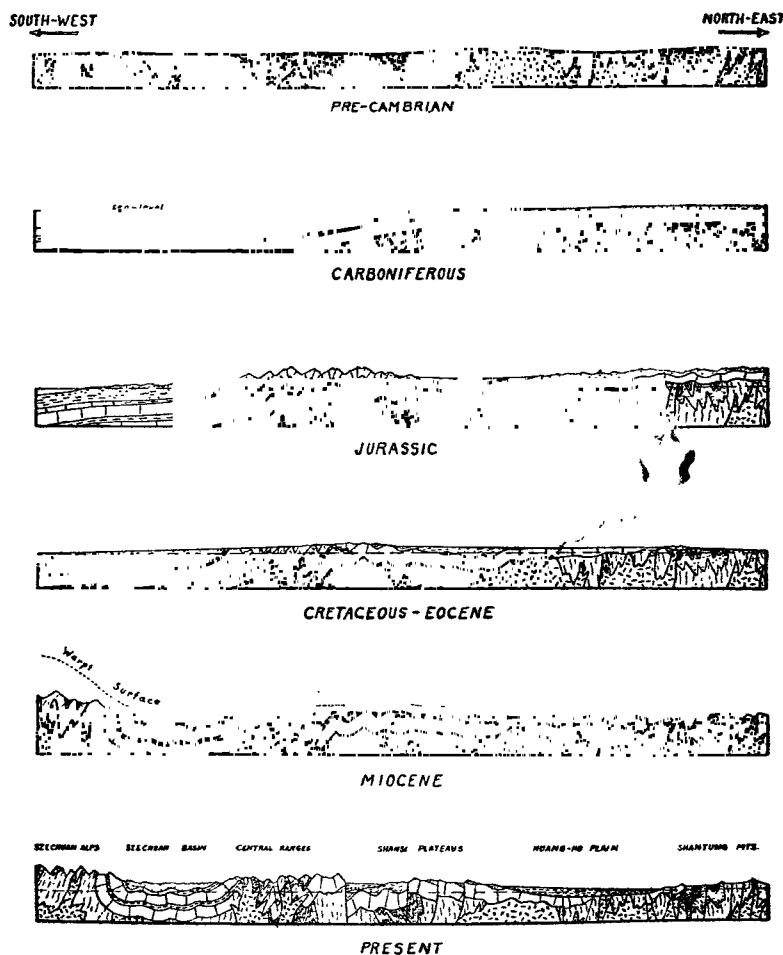
FIG. 2.—DIAGRAMS TO ILLUSTRATE GEOLOGICAL CONDITIONS IN CHINA AT DIFFERENT PERIODS IN ITS HISTORY.

The features are necessarily much generalized and in part hypothetical.

is too sluggish to carry sediment, it is built up until it reaches the required gradient; and on the other hand, if any part has too steep a declivity, it is gradually worn down to the proper slope. In consequence of this law, the parts of China which were slightly bulged above their original levels were reattacked by the branching systems of rivers with renewed vigor. By carving out the softer rocks, these

have made deep valleys with intervening mountain ranges. Some of the larger rivers, such as the Yangtze, maintained their courses in spite of the slow uplifts directly athwart their courses. A result is the magnificent series of gorges along the central Yangtze where the great river has sawed its way through a slowly rising mass of hard, complexly folded rocks.

On the other hand, the broad areas which were depressed not only below the general level of stream action, but below sea level, were rapidly filled with sand, loam, and clay washed down out of the adjacent mountains by the streams. The process of filling the depressions is the exact complement of the process of etching out the highlands. No doubt the rivers have been able in large measure to keep pace with the sinking movement of the ground, so that great rivers like the Hwang may have maintained perfectly graded courses across the region of depression from the mountains to the sea. While thus engaged in building up its channel, the river in time of flood frequently breaks through its low banks, shifts its channel, and then begins to fill up a new and hitherto lower part of its surroundings. By the long continuance of this process of repeated shiftings and fillings, the great eastern plain of China and many smaller plains have been produced. It is here, where the population is densest and the rivers least confined, that the devastation by floods and their attendant famines is greatest.

By this succession of events the surface of China is believed to have reached its modern condition. We may now consider it piecemeal and see how the existing geologic conditions, which are the result of this long series of past changes, influence the habits, occupations, and even mental traits of the people. Because space is limited and also because I have not seen all the physiographic divisions of China, it will not be possible for me, even briefly, to describe each of them. A few are therefore selected to show the range of variety of the whole.

The mountains of northeastern China, typified by the province of Shantung, are unlike those of the rest of the country in several respects. Although the individual peaks are often sharp and rocky, they are generally separated by wide, flat-bottomed valleys. The process of erosion has here gone so far that the rivers have already carried away most of the land, leaving only isolated groups of low mountains. The broad valleys accommodate a relatively large number of people, who congregate in the villages dotting the intermontane plains. In contrast with most mountainous regions, travel between the different valleys is comparatively easy here, because many of the passes are but little higher than the plains themselves, and constitute scarcely any obstacle to progress. Roads are plentiful, and so the cart and the wheelbarrow are the principal vehicles for through traffic.

This is one of the few parts of China where boats can be but little used. The streams are shallow and full of sand bars, and on account of the pronounced wet and dry seasons many of them are intermittent. For these reasons the majority of them are not navigable. The deeply eroded land of Shantung has, however, suffered a relatively recent movement—apparently a sinking of the land—which has allowed the ocean to penetrate the mouths of many of the coastal valleys. This marginal drowning has produced some excellent harbors, such as that of Chefoo, the great silk port, and Tsingtau, the German stronghold.
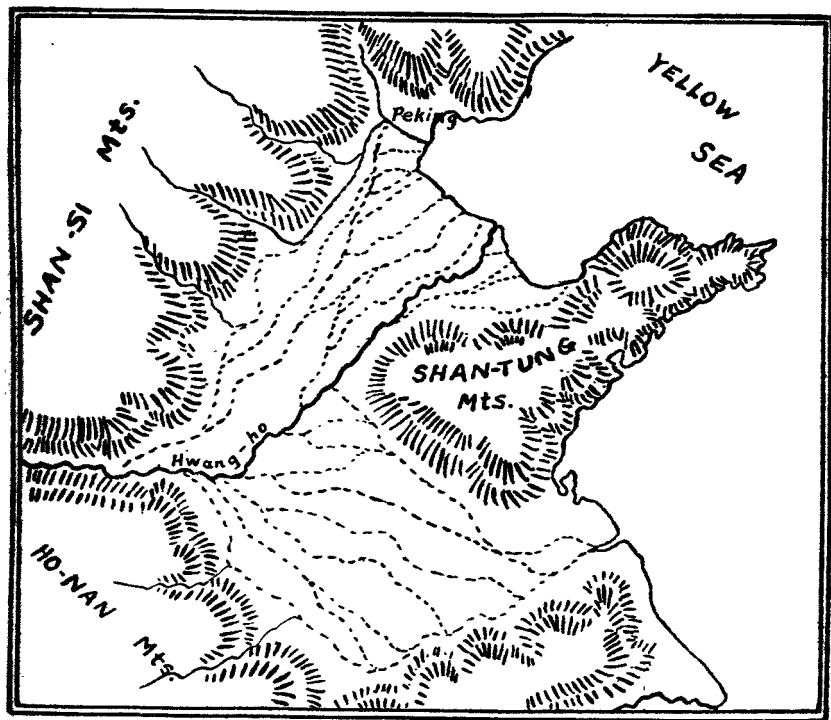
FIG. 3.—SKETCH MAP OF THE SILT PLAIN OF THE YELLOW RIVER.
The dotted lines indicate former courses of the river, as it spread over its alluvial fan.

On the west, and encircling the Shantung hills, lies the great plain of the Hwang or Yellow River, which will serve as the type of many much smaller plains in various parts of China. As explained before, this vast gently sloping plain has been built by the Yellow River and some of its tributaries in an effort to preserve a uniform gradient across the sunken portion of eastern China. Like the Lower Mississippi and all other rivers which are building up rather than cutting down their beds, the Hwang is subject to frequent floods and occasional shiftings of its channel. Its course between the mountains and the sea has thus been changed more than

PLATE 2.

Fig. 1.—Low isolated mountain group in northeastern China.

Fig. 2.—Two farmers raising water from the grand canal into the head of an irrigating ditch by means of a wicker basket slung between them

Fig 3.—A wide River Plain among the mountains of Shan-Tung The bridge of stone slabs across the sand-laden river is part of the principal wheelbarrow road of the valley.

Fig 4 —A typical city wall, with gate tower.

Fig 5 —Heavily loaded freight wheelbarrows with mules for motive power

Fig. 6 —A typical passenger cart.

Fig. 7 —Freight wheelbarrows rigged to take advantage of a favorable wind

Fig 8 —A medium-sized house-boat used on the Yang-tze-Kiang and its tributaries.

FIG. 1.—SOIL RESERVOIRS ON A HILLSIDE IN THE LOESS COUNTRY.
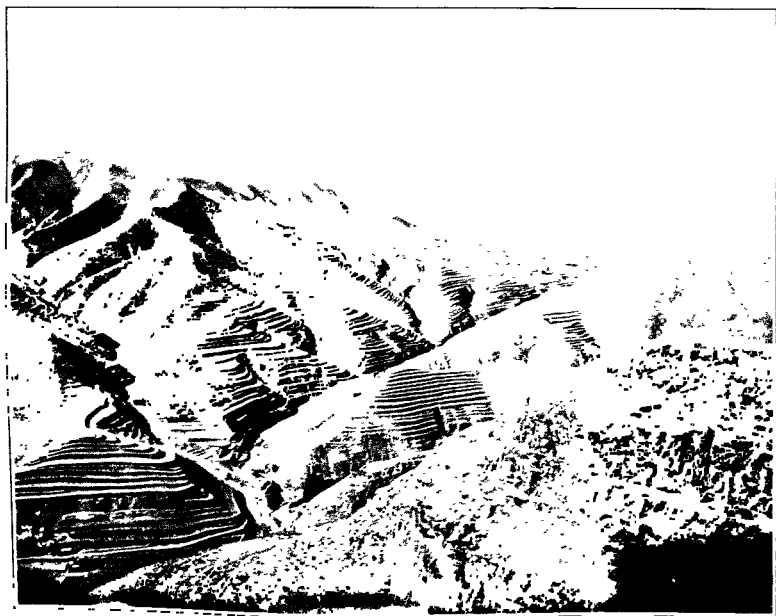
FIG. 2.—MOUNTAIN SLOPES IN NORTHWESTERN CHINA, TERRACED TO PREVENT THE EROSION OF THE LOESS.

fifteen times in the last 3,000 years. In these incessant shiftings the river has strewn all over an enormous area, 500 miles from north to south by 300 miles from east to west, layer after layer of fine yellow loam or silt; the very name " Yellow River," which is a translation of the Chinese " Hwang-ho," suggests the close resemblance to our own mud-laden Missouri. Almost every square foot of this vast alluvial fan is, of course, underlain by a deep and fertile soil, and is intensively cultivated by the industrious Chinese inhabitants. One sees no large fields of grain, such as those on our Dakota prairies, but, instead, thousands of small truck gardens belonging to the inhabitants of the hundreds of little mud-walled villages with which the plain is dotted. The ever-present town walls have doubtless been built, because the inhabitants have no natural refuges, as their mountain cousins have, and their very accessibility has made them in the past the frequent prey of Mongol and Tartar invaders or of rebels and rioters from within their own country.

Since the water supply of the plain is not lavish but little rice is grown there. The dry-land grains and such vegetables as cabbages and potatoes are the staple crops. The small gardens are sparingly irrigated, however, in times of drought, by water taken from the canals or wells, with the help of various types of crude pumps operated by men or by donkeys (pl. 2, fig. 5; pl. 5, fig. 5).

In this densely populated alluvial plain there is practically no pasturage and no woodland. From the very nature of the plain it could not yield coal, which is always associated with the solid rocks. To bring fuel, as we do, from distant parts of the country is impossibly expensive for the Chinese, without an adequate railroad system, and that is still a thing of the future. When the harvest has been gathered in the autumn the village children are therefore sent out to gather up every scrap of straw or stubble that can be used either for fodder or for fuel. The fields thus left perfectly bare in the dry winter season afford an unlimited supply of fine dust to every wind that blows. This is doubtless the explanation of the disagreeable winter dust storms with which every foreigner who has lived in northern China is only too familiar.

Although carts and wheelbarrows are much used on the Hwang Plain, their traffic is chiefly local. That may be due in part to the fact that the numerous wide and shifty rivers are difficult to bridge, while ferrying is relatively expensive. Another, and perhaps more important, reason is that the rivers, and particularly their old, abandoned courses, afford natural waterways which are available nearly everywhere. By taking advantage of these or by deepening them, and in some places by actually digging canals through the soft material of the plain, the Chinese have put together the wonderful system of interlaced canals for which they have been renowned since

Europeans first visited them. The thousands of junks which ply these waterways maintain a volume of inland commerce, which is inferior only to that of the great railroad countries, such as the United States. The relative freedom of communication in this great plain of the Yellow River has helped to bring about a greater homogeneity in the people than in any other equally large part of China. Here we find a single dialect in use over the entire region, whereas in some parts of southern China the natives of even adjacent valleys speak languages almost unintelligible to each other. The other common effects of isolation, such as the lack of acquaintance with the customs of outside peoples, the hatred of foreigners, the peculiar local usages, and many other things, are less prominent here than in other parts of the empire. Excepting the coastal cities, there is no safer part of China for foreigners to travel through.

West and northwest of the Yellow River Plain lie the more rugged plateaus and mountains of northwest China, with their subarid climate presaging the approach to the deserts of Mongolia. Over much of this region the ancient limestones and sandstones are still horizontal or are gently folded, with occasional dislocations along faults. On account of the comparatively recent uplift and differential warping which this part of China has suffered, the streams have been greatly accelerated in their work, so that they have hollowed out canyons in the raised portions and have filled in the depressed basins with sand and silt. This is the region celebrated among geologists on account of the loess, or yellow earth, which lines the basins and mantles the hillsides everywhere. It is believed that this is very largely a deposit of wind-blown dust, although it has been worked over considerably by the streams from time to time. No doubt Baron von Richthofen, the distinguished German explorer, was near the truth when he concluded more than 40 years ago, that the "yellow earth" was the dust of the central Asian deserts carried into China by the northwest winds. The presence of the loess determines, in large measure, the mode of living adopted by the inhabitants. Because of its fertility and moisture-conserving properties, it is well adapted to dry farming, and there is little water for irrigation. The Chinese are not content with using the level bottom lands, but successfully cultivate the hillsides wherever a deposit of the loess remains. In order to prevent the soil from washing off from these steep slopes, they build a series of stone walls, thus forming soil reservoirs or terraces. In this way nearly all of the soil is utilized.

In such a country rivers are not numerous and those which exist have many rapids and shoals. Boats are therefore but little used in northwest China. For both passenger and freight traffic, pack animals or rude vehicles are the chief reliance. For passengers there are also the palanquin or sedan chair and the mule litter. Where the

Fig. 1 —Cave houses in the loess, faced with stone.
Fig. 2.—Men and donkeys carrying coal from the mines in Shansi.

Fig. 3.—A pack train of donkeys, on the imperial highway over the Loess Plateau.
Fig 4 —A roadside village and small fields at the bottom of the mountain valley
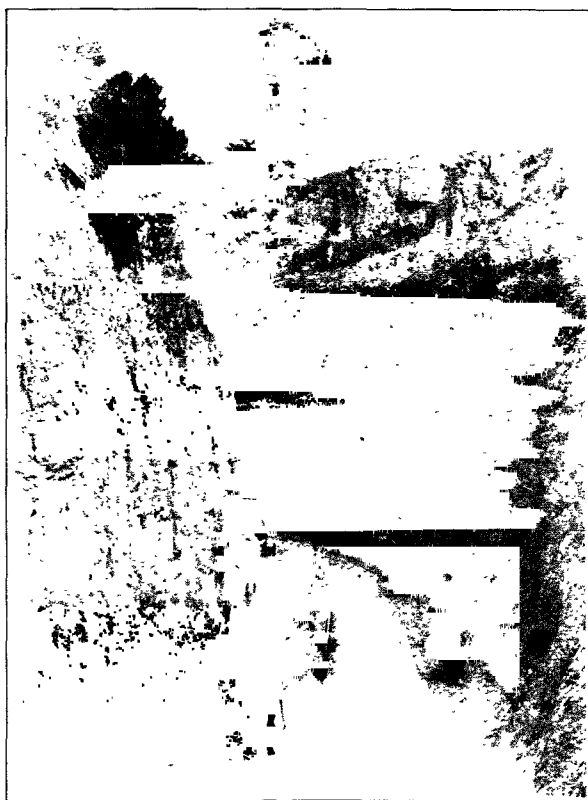
FIG. 5 —A ROADWAY SUNK DEEP INTO THE LOESS BY CENTURIES OF TRAVEL.
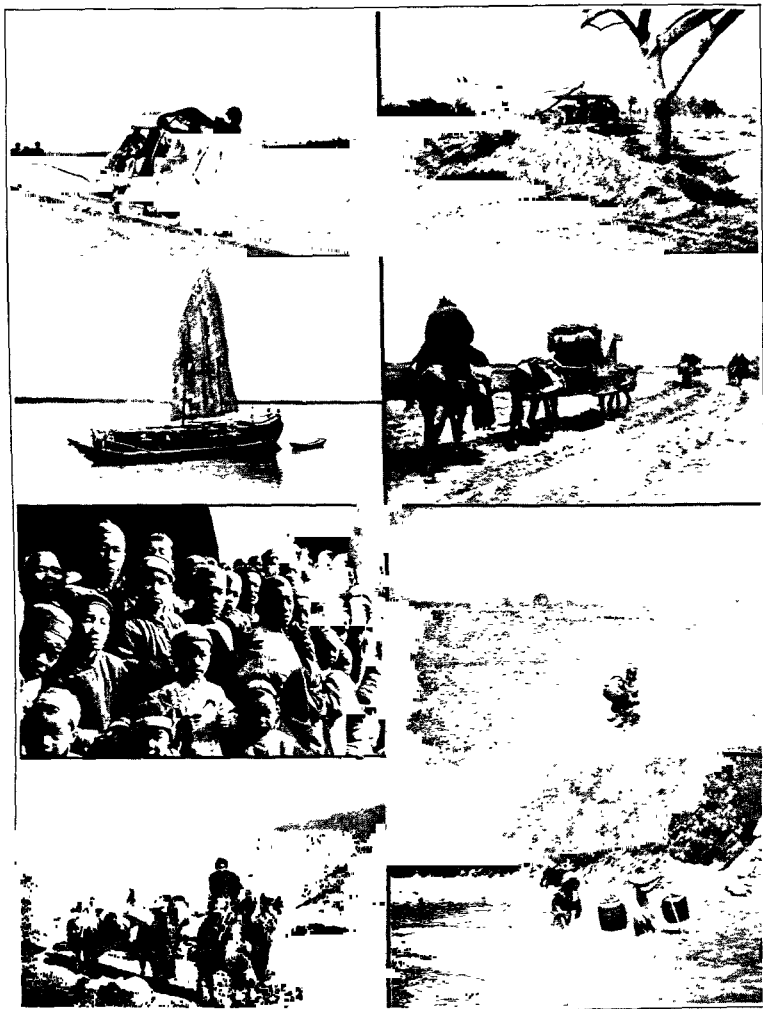
Fig. 1 —A two-man wheelbarrow carrying a merchant and his stock of goods.
Fig. 2 —A river junk.
Fig. 3 —A friendly crowd in an inland town.
Fig. 4 —Mongolian camels in northwestern China.

Fig. 5.—Irrigating with water pumped from a well.
Fig. 6 —A sedan chair swung between two mules.
Fig 7 —Getting his initiation into farming with grub hook and basket.
Fig. 8.—Coolies fording a mountain river.

country is not too rough, the two-wheeled cart is the usual conveyance for merchandise. Over the mountain passes, however, and in many of the smaller valleys, roads are so narrow that carts can not be used, and so here pack animals, particularly horses and mules, are substituted. The traveler in this part of China is often reminded of his proximity to Mongolia by the frequent sight of camels. They are nevertheless not indigenous beasts of burden and the inhabitants themselves do not use them.

In consequence of the swampy state which prevailed in this part of China far back in the carboniferous period, thick deposits of coal were formed. These are now exposed in the deep valley slopes between beds of limestone and sandstone, and the circumstance has made Shansi Province the principal coal-producing district of China. The coal is mined by very primitive methods and as there is still no adequate system of railroads in this or any other part of the empire, the product can be transported only in carts or on pack animals. Either of these modes of carriage is so expensive that it becomes unprofitable to transport the coal more than 60 to 100 miles from the mine, and so the denizens of a great part of northern China, where fuel is scarce and the winters are severe, are no more able to obtain it than as if the United States contained the only coal fields in the world. The advantages that will accrue from the building of railroads in northern China are many, but one of the greatest will be the wide distribution of this essential fuel.

In going south by west from the plateau country, one enters a region of warmer climate and more generous rainfall, which, for want of a more distinctive name, I have called the Central Ranges. This is the part of China which was particularly affected by the rock-folding movements of the Jurassic period, and which in a much more recent time has been reelevated and therefore newly attacked by the streams and other erosive agencies. Broadly regarded, it is a complex of sharp mountain ridges and spurs with narrow intervening valleys. The ridges are not so high, however, but that they are clad with vegetation, and the scenery is therefore not alpine. The surface is nevertheless very rugged and its internal relief averages at least 3,000 feet. The roughest parts of our Carolinas resemble it in a measure. In such a region obviously there is no room for a dense population. Wherever there is a little widening of the bottom of the valley there is a farm or occasionally a small village, and even the scattered benches high up the mountain sides are reached by steep trails and diligently cultivated. But even when all of these are combined, the total area of land under settlement is relatively small.

In this region there are no railroads whatever, and although wagon roads could be built in some places, they would be expensive, and the Chinese have not yet attempted to make them. All travel and com-

merce, therefore, depend on the agency of pack animals or coolies, and
the roads they follow are mere trails winding around the steep moun-
tain sides or threading the bottoms of narrow valleys, where swift
streams must be forded at frequent intervals. Under such circum-
stances it is evident that there can be but little effective traffic. Only
comparatively light and expensive articles can be transported long
distances. Around the edges of the mountain mass where the popu-
lous cities of the adjoining plains can be reached with one or two
days' travel there has been for centuries an important trade in lum-
ber. The mountains have now been so largely deforested, however,
that it is necessary to go farther and farther back into the heads of
the valleys to find large trees. Hence only the more expensive kinds
of lumber such as coffin boards—which are absolutely indispensable,
even to the poorer classes—can profitably be brought out. These are
often carried for 20 or 30 miles on the backs of coolies—a costly mode
of transportation. The smaller trees and brush the mountaineers
convert into charcoal, which they carry on their own backs down to
the towns along the foothills.

Lack of transportation facilities is doubtless the chief reason why
the opium poppy has in the past been widely cultivated in this part
of China, although the practice has lately been prohibited by the
Government. The advantage in poppy culture was that it could be
carried on in small scattered fields and the product was so valuable
for unit of weight that it would pay for long-distance transportation
across the mountains. The inhabitants of the region themselves were
not, however, generally addicted to the use of the drug.

The rainfall of the central mountain region is sufficient to supply
the many springs and tributary brooks of which the people have
made use in irrigation. The mildness of the climate here permits the
growing of rice, and by terracing the hillsides they are able to make
a succession of narrow curved basins, in which the aquatic crop may
be grown. For the cultivation of rice it is necessary that the fields
be completely submerged during part of the season, and so there must
be a plentiful supply of water.

On the larger rivers, such as the Han and the Yangtze and their
chief tributaries boats are successfully used. In fact, the Chinese
river boatmen are so skillful in the handling of their high-prowed
skiffs that they navigate canyons full of rapids which most of us
would consider too dangerous to attempt. The descent of one of
these rivers is an easy although exciting experience. The return trip,
however, is slow and laborious, for the boats must be dragged up-
stream by coolies harnessed to a long bamboo rope, which has the
advantage of being very light as well as strong. In the many places
where the river banks are so precipitous that it is impossible to walk

PLATE 6.

A VALLEY IN THE TSIN-LING MOUNTAINS OF CENTRAL CHINA.

Small cultivated fields may be seen on benches high above the river.

FIG. 1 —COOLIES CARRYING FREIGHT ALONG A MOUNTAIN TRAIL WHICH HAS BEEN PARTLY WASHED OUT BY A TURBULENT STREAM.
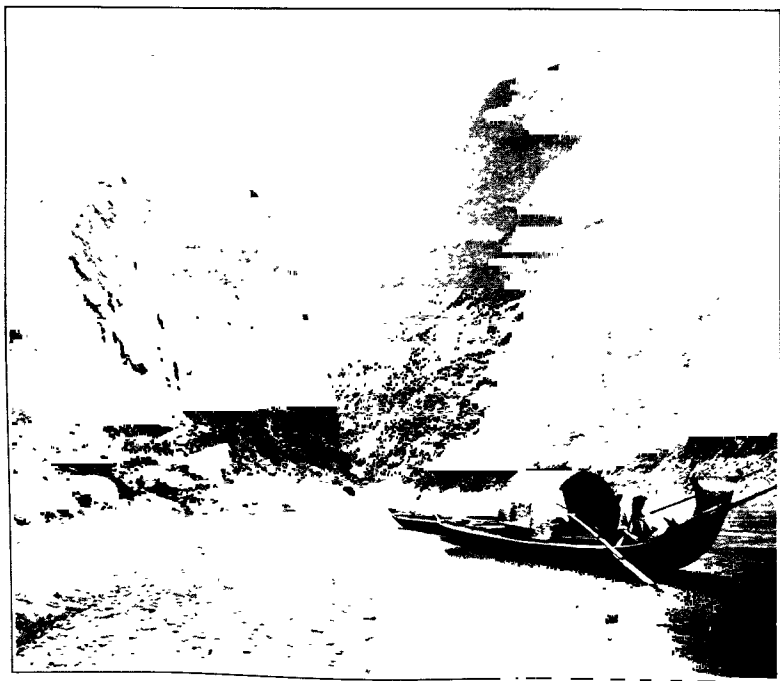
FIG. 2.—RIVER SKIFFS IN ONE OF THE LIMESTONE GORGES OF THE CENTRAL RANGES.

PLATE 8.
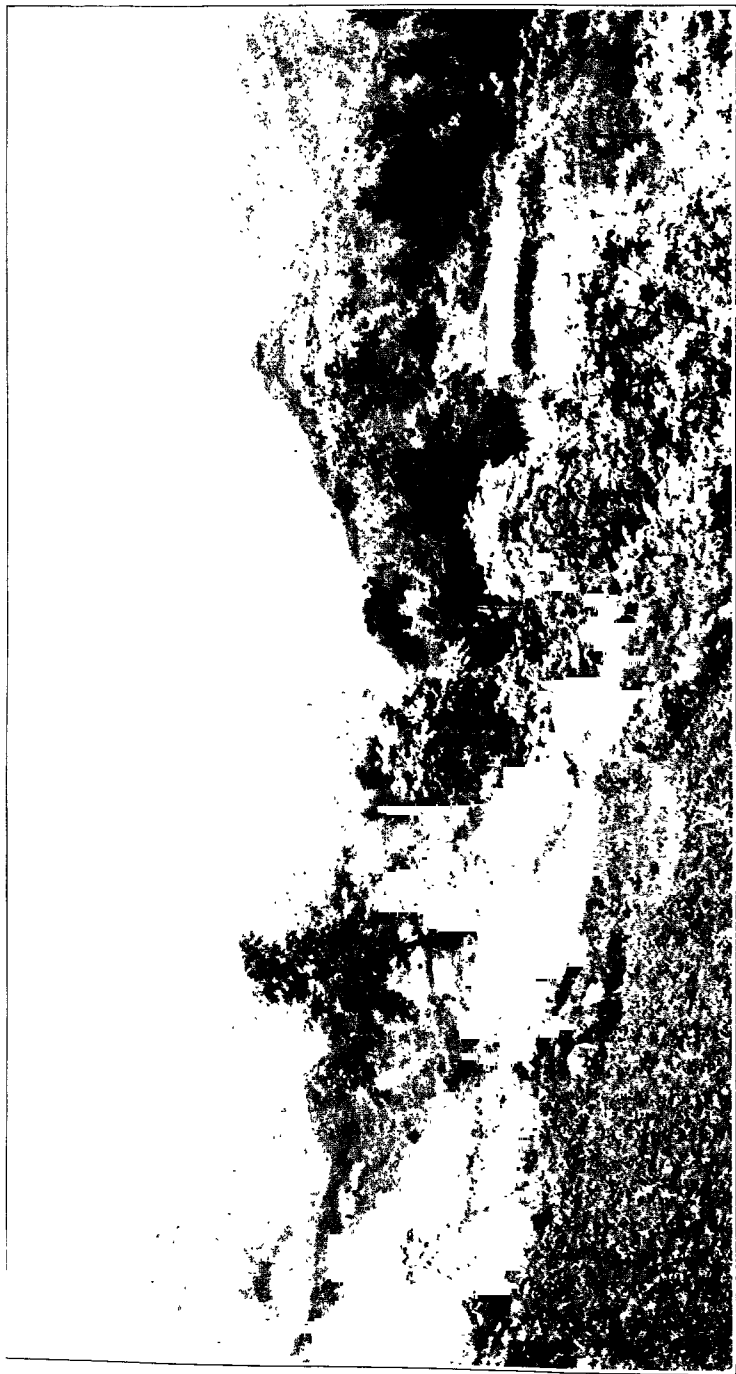
AN OPEN VIEW IN THE MOUNTAINS BORDERING THE BASIN OF SZECHWAN.

FIG. 1.—A VALLEY IN THE CENTRAL RANGES.

In the foreground are a series of terraced rice fields now filled with water.

FIG. 2.—ONE OF THE GREAT LIMESTONE GORGES THROUGH WHICH
THE YANG-TZE-KIANG PIERCES THE CENTRAL RANGES.

along them it becomes necessary for the boatmen to pole around the cliff or to zigzag from one side of the river to the other to take advantage of every foothold.

Through the central part of this mountain uplift the great Yangtze River, which in its lower course readily accommodates large ocean-going vessels, has carved a succession of superb gorges. In many places the gray limestone walls rise from 3,000 to 4,000 feet above the river, and the stream is compressed into less than a tenth of its usual width. Difficult and dangerous as are these canyons, beset with rapids and whirlpools, they afford the only ready means of communication between eastern China and the fertile basin of Szechwan, which lies west of the Central Ranges.

Without the highway of the Yangtze this great Province, four times are large as Illinois and with more people than all of our States east of the Mississippi River, would be unable to export its many rich products or to enjoy the commerce of outside Provinces and nations. It has been effectually barred off from India and Burma by the succession of high ranges and deep canyons which appear to be due primarily to the great epoch of folding in the Miocene period. Szechwan is a broad basin which has never been depressed low enough to force the streams to level its bottom with alluvial deposits, as in the Yellow River plain to the east; nor does it seem to have been elevated into a high plateau which would have been carved by many streams into a rugged mountain country. The soft red sandstone beds which underlie it have therefore been sculptured into a network of valleys with intervening red hills or buttes. With a climate as mild and moist as that of Alabama, and a diversified topography, there is opportunity for many industries and for the cultivation of a great variety of crops. Szechwan leads all the Provinces in the exportation of silk. Here grow the lacquer and oil nut trees and a wide range of field and garden fruits, grains, and vegetables. Ample water for irrigation and especially for rice culture is supplied by the many perennial streams which descend from the encircling mountains. These uplifted and now mountainous tracts have also served as a barrier to invaders from all directions, so that this has been less subject to wars than almost any other part of China, and hence has been more stable in development. Its inhabitants are among the most substantial and progressive components of the Chinese nation.

We now come to the last of the geologic divisions which were laid out for consideration. From the Szechwan Basin southwest to the confines of India there extends a series of high mountain ranges separated by deep and narrow valleys, all trending in a south or southeasterly direction. Although not so high above sea-level as the mountains north and south of Tibet, these ranges are an even more effec-

tive barrier to travel because they are so continuous and the relief is so great. Not only is there no waterway but there are no wagon roads, and the building of a railroad would be a stupendous and expensive engineering task. Such a road would necessarily involve the making of a succession of long bridges and tunnels. Here, as in the central ranges, settlements are limited to the rare open spots in the bottoms of valleys, and so the population is sparse indeed. The total commerce is very small in volume, because goods must be carried almost entirely on the backs of coolies. The rugged characteristics of the region are evidently the direct result of the recency of the compressive movement which produced the tremendous mountain folds, and perhaps are still more due to the renewed uplifts which have permitted the streams to continue the carving of their deep gorges. This part of China is geologically very young, and to quote the words of the distinguished old geologist of California, Joseph Le Conte, " the wildness of youth (here) has not yet been tempered by the mellowness of age."

THE PROBLEMS OF HEREDITY.[1]

By Dr. E. APERT,[2]

Principal at Andral Hospital, Paris. Secretary General of La Société française d'Eugenique.

It is my pleasure to address you, ladies, on a most attractive subject—heredity. What is more interesting than to study a child's physical, intellectual, and moral resemblance to either of its parents (direct heredity), to its more or less remote ancestors (atavic heredity), or to its uncles, aunts, male or female cousins (collateral heredity)? What is more enthusing than to search out the reason why and how this resemblance is brought about? And yet it was with some hesitancy that I accepted an invitation to speak to you on this subject. I feared to impose upon you, at least in the second part of my address, some difficult, abstruse, mathematical explanations, compelling me to put before you some rather formidable looking algebraic symbols, which will demand your closest attention. If I consent to talk to you of heredity. as I have been obliged to do for a dozen years, it certainly would not do for me to tell you of curious and amusing facts without giving other explanations than unverified theories. We are beyond that, and you would have me at once make you acquainted with recent advances; the result of experimental studies on animals and plants and their explanation requires a knowledge of natural history ideas and of general biology which I will be obliged to recall to you; but these discoveries are applicable just as much to the human species as to the more humble animals and plants. I will therefore explain them to you in detail.

I would, perhaps, have passed over in silence that most difficult part of the subject if I had been called to speak before a frivolous worldly audience. But I have before me here an assembly of the very highest type. I know that you are ladylike women who do not wish a lecturer to divert or amuse you, but to instruct you. You come here to acquire knowledge which will enable you to be useful to all, to your surroundings, to your neighbors, to your country. Every day you prove that you do not fear the trouble you take. It is not much to exact a little attention from you, since you do not dread the

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[1] Translated by permission, with author's revision, from Revue Scientifique, Paris, July 12, 1913.

[2] Lecture before " l'Union des Femmes de France " (French Red Cross).

difficult care of the sick or injured, the dressing of wounds, the groans of those operated upon, or the death rattle of the dying. I recall that several of your members are at this moment on the field of battle, and have no fear of facing climatic dangers and enduring hardships even unto death.

You know that the laws of heredity are susceptible of happy applications in the human species, so that you will not doubt, I am sure, some explanations that I shall give as briefly and as clearly as it is possible for me to do.

Heredity. What is meant by that word? You know what it is. It is a fact of daily occurrence, that the descendants reproduce more or less completely certain peculiarities which existed in one or the other of their ancestors.

There is right here a point of observation so universal, so generally known, that it is never overlooked, after the birth of a new-born child, to ask who it resembles. Is it the father? Is it the mother? Generally, persons who have known the father as a child are of the opinion that the newly born is exactly like its father at the same age. On the other hand, those who knew the mother do not hesitate to say, " But no; that little mouth, those large eyes, are they not its mother's? There is a most striking resemblance." In reality both of these observations are correct, and we shall see that mathematically the child has exactly one-half of the characteristics coming from the paternal and one-half from the maternal line. If, in certain cases, very rare, however, the child seems to have inherited more from one side than the other, it is because certain characteristics are susceptible of remaining latent, masked, invisible; but they exist none the less, and generally these latent characteristics include some paternal and some maternal characteristics, so that in the great majority of cases the child after all is an equal mixture of both parties, a mixture sometimes happy, sometimes, alas, unfortunate. It is these unfortunate cases that a knowledge of the laws of heredity may in some degree restrain.

Heredity bears not only on the features but on the physical characteristics, the build, weight, tints of the skin, the eyes, the hair, etc. It rules also the intellectual side, the morals, morbidness, etc.—in a word, all that constitutes individuality.

Certain individual characteristics may be transmitted for many generations. The ancients have preserved to us the history of this transmission in the Cicero and Lentulus families by some marks on their countenances, to which they owe their name (" cicer," chickpea; " lentulus," lentil). In the same way a lock of white hair at the middle of the forehead of the youth was for a long time transmitted, they tell us, in the family of the Rohans. But these family characteristics are not long in disappearing, which can be understood,

for at each generation the women are carrying half of an hereditary element which is exempt from the peculiarity. The extraordinary part of it is that in the cases cited these peculiarities have not disappeared sooner.

On the other hand, it is very natural that some peculiarities should be perpetuated where marriages take place within a limited circle and where the same families constantly intermarry for several generations. This is seen in certain regions, but the facility of intercommunication tends, however, to render such conditions more and more difficult. The populations of certain of our coast islands (Ouessant, Brehat) have for that reason taken on a special type. Nearly all the inhabitants of a valley in the high Alps show what they call sex digitism; that is, an extra finger and toe. Emigration toward the cities has caused these people to disappear. Sometimes certain family groups are found isolated from the rest of the population not only by geographical obstacles but by their costumes, manners, and differences of religion. They may begin to take on a certain type even when they are primitively of the same race. Thus the Mohammedans of China, who are not immigrants, but pure Chinese, have a special type of feature; the Parsees of India, who are of the same Indo-European race as the Brahmans, are of a type very different from them; the Polish Jews, who are not the immigrant Israelites, but who are descended from tribes converted during the tenth century of our era, partly to Christianity, partly to Judaism, have ended by separating themselves from their brothers, the Polish Catholics, not only in their physical characteristics and their intellectual aptitudes but also by their special disposition to certain diseases peculiar to them and which form part of a group of familiar nervous maladies that I will mention in a moment.

There is a group of families which have intermarried almost exclusively for nearly 1,000 years. They are the royal families of Europe. This group presents a very important and particularly interesting subject of study on account of the quality of the persons composing it and because of the facility with which their history and even their portraits can be traced back to a very early period. In a highly authoritative work Mons. Galippe has brought together more than 200 portraits of members of the royal houses of France, Spain, Austria, Bavaria, and Savoy, who have united with each other by repeated marriages in nearly every generation. It is easy to see that a family resemblance was very quickly manifested. It is characterized principally by two peculiarities, the arched nose, the Bourbon nose, which is found not alone among the Bourbons, but among the royalty of all the Catholic thrones of Europe, and also the projection of the very heavy lower jaw, the teeth projecting over those of the upper jaw. The portrait of Philip II of Spain at the Louvre

and the portraits of Charles V show this peculiarity most strongly, and it is still found more or less characterized in the great majority of members of royal families, as much among the great houses that we have mentioned as on the small thrones of more recent foundation where they are at once fixed by repeated alliances.

You see, *the peculiarities persist in successive generations only when they exist at the same time in the paternal and maternal ancestors.* In the inverse case they rapidly disappear.

In what concerns the intellectual faculties we reach the same conclusions. We could cite numerous examples of families where the same order of talents has appeared among several members. Among literateurs. the two Plinys (uncle and nephew), Seneca and his nephew Lucien, the two Corneille brothers and their nephew Fontenelle, the two Chénier brothers. the two Musset brothers, the two Alexandre Dumas, father and son, and many others. Among learned men we find the physicists Becquerel, grandfather, father, son, and grandson; the mathematicians Bernouilli, uncle and three nephews or grandnephews, and the naturalists Geoffroy-Saint-Hilaire, Isodore and Etienne, father and son. Among painters are the three Vernet, Carl, Joseph. and Horace. We could lengthen the list very much, but the persistency of high talent seldom persists more than three generations. In order that this may be otherwise, the inheritance of a certain talent must be maintained by the union of families equally endowed. We could mention several examples of this. Thus the Darwin and the Galton families, both of which include eminent naturalists, have been thus united repeatedly. Here we find the persistence of remarkable faculties relative to natural history for five generations, since Erasmus and Robert Darwin, both naturalists of high merit, grandfather and father of the illustrious Charles Darwin. down to the sons and grandsons of the latter, one of whom, George, has recently died after achieving some remarkable work in natural history, and another, Leonard Darwin, who presided recently at the meeting of the Eugenic Congress in London. The Galtons likewise were perpetuated by Sir Francis Galton, grandson of Charles Darwin through his mother. It was he who founded the Eugenic Laboratory of London, and accumulated numerous works on heredity, from which the greater part of the facts that I will relate to you are borrowed.

The most beautiful example of mental heredity is that of the Bach family, the musicians. The beginner was Veit Bach, a baker at Presbourg, who refreshed himself after his toil by his songs and music. He had two sons, who commenced that unbroken line of musicians of the same name which spread over Thuringe. Saxony, and Franconia for nearly two centuries. Fifty-seven musicians of that family

have left a record and twenty-nine are mentioned by Galton as eminent musicians.

The Bachs contracted numerous marriages for their daughters with former music masters, organists, and town musicians, as the custom of the body corporate at that time permitted. Those frequent marriages among musicians could not help having great influence upon the musical talent of their offspring, and this, says Mr. Ribot, is one of the most beautiful examples of artificial or natural selection that one would find in the human species.

We now come to heredity of moral characteristics. Morality is transmitted in families; an honest father and mother have good sons and daughters. Of course education and good example have their share in it, but so also does heredity. Inversely, bad principles are transmitted in families, and we read in every book on heredity the history of that mendicant who arrived in the English colonies of America in the early days of their colonization, and who, endowed with all vices—a drunkard, a thief, and debauched—had passed half of her long life in prison. She had had numerous children, and in looking over the civil archives of the State and also those of the galleys and prisons we can safely state that among several hundred of her descendants four-fifths were delinquents for misdeeds of various kinds and a dozen had ended their lives on the gallows.

Permit me here one digression. It suggests a subject which has been much considered—that of responsibility. Since tendency to crime is inherited, since there are born criminals, are they responsible for their crime, and should they be punished? Are they responsible? The question should be considered from two very different standpoints. There is the philosophical point of view. It is possible that from that view, we might say that responsibility does not exist, for all our acts are determined by causes and that our will is only an illusion. I will not discuss this, for centuries since the time of ancient philosophers have not sufficed to settle it, and I have no desire to enter into the controversy of the free will, of the efficient cause, and the determining of our acts. That phase of the question, however, ought by no means prevent us from responding when we consider the practical point of view. On this side the more the delinquent has acted through the fact of tendency due either to heredity, environment, or to education, the greater the need that he fear chastisement, for it is only such fear that restrains the immorally born person. The accidental delinquent should certainly be punished, but his punishment is not a social necessity; for the punishment of being a born criminal is forced upon him; it is rendering him a service to furnish him the only reason that he has for struggling against his bad instincts. The only irresponsible beings are delinquents who have

lost all consciousness of their acts, epileptics for example, who in their normal state have no recollection of what they may have done during their frenzy, and also certain insane persons. There remains for me the discussion of the inheritance of diseases, an interesting phase of the question of heredity, because of its many practical and important applications. We should distinguish, on the one hand, between inherited maladies, known as family diseases, which seem to have no other cause than that of heredity, and, on the other hand, the much more common illness where heredity plays only a predisposed or accessory part and is merely a factor among other more active and more important agents.

Charcot has described, under the name of " family maladies," certain affections of the nervous system; they habitually attack a considerable proportion of the same family (25 or 50 per cent). They take similar form and a like evolution with each of the stricken subjects. They appear among these persons as the result of taint originally from a germ, becoming manifest through their development and independent of all exterior action.

Since these first works of Charcot, the known number of diseases with these characteristics has very much increased. Many family affections are now known, not only of the nervous system but of all organs of the body. These family maladies are transmitted in families in the same manner as morphological characteristics; they are inherited under the same laws as malformation, such as the sixth digit, already mentioned. As to malformations, they may pertain more particularly to certain countries, certain races, and certain groups of people, and especially to groups of people isolated by their geographical locations or by their matrimonial customs. There is nothing strange in the way that these malformations are manifest, for they are the result of veritable inherited malformations. Thus, there is a family disease called "l'atrophie papillaire familiale," and which, with very few exceptions, attacks men only; the women of these families are almost always exempt, and I will tell you to what this happy privilege is due. The children of these families are born normal and grow up full of health, but toward the age of 25 the sight of some of them begins to weaken; if they consult an ophthalmologist he discovers, after exploring the depth of the eye, an atrophy of the central bundles of the optic nerve and, in spite of all that can be done, that weakness progresses until there is almost a complete loss of sight. One is led to believe that the disease comes from some special physical defect—to an exaggerated narrowness of the cavity where the optic nerve leaves the cranium. This cavity remains in a fibro-cartilagenous condition during childhood; in men the ossification of the circumference of the orifice is completed toward the age of 25; but in women it more often remains incomplete. The malady

is, then, the result of a gross, anatomical malformation. All family diseases thus have for their origin an hereditary malformation, though often it is not so easily revealed and is discovered only by microscopically examining the inmost of the tissues. But in either case it is a question of the transmission of a special defect, and there is nothing wonderful in the fact that it is transmitted according to the same laws as physical peculiarities.

There are other diseases inherited in an entirely different way. I will commence with microbe diseases. In these diseases the affliction which has stricken either the father or mother, or both, is transmitted to the child through an entirely different process. It is really contagion. In certain diseases the mother, carrying some deadly germ (which she may or may not have received from the father of the child), contaminates her child before its birth. That is most usually the case on the average. I do not insist upon it. These cases are known as "heredity contagion." Oftener still, the child is born safe and sound, and it is only during the course of the first months or the first few years that it is contaminated by one or the other of its parents. It is apparent that it does not seem to be more than pure heredity. Tuberculosis is like that. You know how tuberculosis appears to be inherited. In your Red Cross dispensaries you find that entire families are now and then decimated by tuberculosis; the father or mother, or both, are ill with pulmonary tuberculosis; the new-born children die of tuberculosis meningitis; if they escape that, they show signs toward the fifth, tenth, or twelfth year of " King's evil," or tuberculosis of the glands; of Pott's disease, osteotic tuberculosis of the vertebræ; of coxalgia, arthritic tuberculosis of the hip, etc.; and at last, during their youth, they succumb to pulmonary tuberculosis. Such facts are unfortunately reported each day, and we understand how belief in the inheritance of tuberculosis has permeated the mind. In reality heredity here plays only a restricted rôle, as I will show you. The great secret in its spread is contagion. A proof of it is that the disease is communicated just as easily to persons who live with a tuberculosis family, though they have no relation to it. Sometimes it is neither the father nor the mother who is the source of disease which has stricken their children successively, but it may be a governess or a domestic affected with tuberculosis. I once knew of a family free from tuberculosis where a young widow returned to her father's home after having been married a year to a tuberculosis husband, from whom she had caught the germ of the disease; she communicated it to her two young brothers, who died, and then to her mother, who at present alone survives her three children. One could relate innumerable instances of this kind. I do not wish to say that heredity has nothing to do with tuberculosis. It influences more or less a resistance to the disease. In some families we

see certain forms of tuberculosis galloping from the start with such rapid strides that no treatment can check them. Repeated contamination, colonies of bacilli that have crept in, certainly may be the cause of it, yet it is believed that there exist some soils favorable through heredity to the growth and spread of the bacilli. But if children of tuberculous parents are protected as much as possible from infection of the bacilli, we have found that the disease has not developed in them. My teacher, Grancher, believed this, and with that idea he founded the " Oeuvre " for the protection of children against tuberculosis. That foundation takes children from homes where the sick father or mother by coughing is spreading the bacilli; it raises these children in peasant's homes in chosen localities in the country. It is demonstrated that these children show a much smaller proportion of tuberculosis than the population taken as a whole.

In short, in the propagation of microbe diseases in families, heredity, properly speaking, plays but a very limited rôle. The propagation of disease is due to contagion, heredity contagion for certain diseases, but, more often still, common contagion, and this rule applies particularly to tuberculosis.

I have to speak to you now of another deduction where the diseases of parents may affect the condition of the child. When the parents at the time of procreation are in a bad state of health they give birth to children who have what has been called " the defects or scars of degeneracy." This is not really inherited, for it shows no resemblance between parents and children. On the contrary, the children in these cases have strayed from the type of people to which their parents belong; they develop abnormal characters, which show that they are different from the usual conformation of their race and species, and even that of the normal human being. This is the literal significance of the word " degeneracy."

It is degeneracy, for example, which is seen in descendants of drunkards. The question is really not one of heredity, but of precocious intoxication from a germ or, to state it better, from sexual cells which are developed in a manner modified in their normal composition by alcoholic impregnation. All kinds of intoxication act the same—intoxication from opium or morphine, the professional intoxication from tobacco (from workmen in tobacco manufactories), or from lead (workmen employed in the making of red or white lead). A proof that intoxication from the germ is the cause of it rather than heredity is that intoxications in youth show the same result. Early alcoholism develops vices analogous to those due to alcoholism in the parents; chronic microbe diseases succeed, like intoxication, in seriously affecting the internal life. Syphilis in the parents (even when it has ceased to be contagious, which seems to prove that the microbe is no longer the cause of it) may also produce " degene-

rate scars" upon the infants, and likewise cause serious infections of youth, chronic gastroenteritis, "athrepsia," etc.

These facts show us that heredity only preserves its power when the infant possesses normal conditions for its development identical to those that their parents had. Otherwise the child ceases to resemble them; he is degenerate. This is opposed to inherited transmission.

This distinction is important, and it becomes much more important to dwell upon it since able authors do not appear to have found it out. I have spoken to you of the excellent and very interesting work of Mons. Galippi. Everything is perfect about it save the title. Mons. Galippi has called it "Hérédite des stigmates de dégénérescence et les Familles souveraines" (Heredity of the stigmas of degeneracy and the royal families). Now he shows us a certain conformation of the face transmitted by heredity, a similarity to one another through many generations of the same line. It is the transmission of a family characteristic; it is directly opposite to that which transpires from the "stigmas of degeneracy." These stigmas momentarily separate some descendant from the normal family type. If the distributing influence which has deviated these subjects from the normal type ceases to act, their descendants return to the normal type. We have seen this in certain groups of peoples subjected to defective hygienic conditions; thus the malarial regions of the Bresse, the Dombes, and the Landes were inhabited, before the sanitary improvements were made, by a small-sized race, many of whom had various malformations described under the name of stigmas of degeneracy (the registers for army service at the time show this). From the time when these countries were made healthy by draining the swamps, the new generations became of normal size and now there are no more exemptions from military service for constitutional defect in those cantons than in those places which have never been touched by malaria. These facts are strictly analogous to a very great degree to those seen in certain animal or vegetable species. There exists (I mention this example among a thousand others) a species of crow-foot which, when the seed sprouts in submerged land, has lacinated leaves altogether different from the ordinary leaves of the plant when grown in dry soil. If made to grow in submerged land for a number of successive generations as long as the experiment permits, and if the seeds are gathered at each generation, those seeds which were sowed in dry land would surely produce full leaves without the number from the lacinated generations having any influence. The lacinated state, then, is a condition of degeneracy which exists only when a cause provoking it exists. Heredity plays no part in its propagation. It is important to distinguish these facts from facts of heredity or they will become complicated.

This is one of the reasons why the observance of traits from heredity is so difficult. They are complicated by the intervening of such numerous disturbing elements that the laws of heredity can be established only by experimenting on some cases simplified as much as possible. That is what Mendel has done. Before showing you the very simple and suggestive laws discovered by Mendel, I ought to tell you in a word the work of the investigators who preceded him.

Naturally, I can give you only a brief and necessarily incomplete sketch of this history.

About the middle of the last century there were many students engaged in researches on heredity. Lucas published (1850) a book entitled " De l'hérédite " (On Heredity), in which he showed that the condition of the descendant results from the combination of two factors: (1) " Heredity," which brings about a resemblance between the subject and its parents and ancestors; (2) " innéite " (inherent), causing a dissimilarity. Thanks to the innate idea, we see in some families certain members who show no characteristic peculiar to the family. We now know that that theory is based on some deceitful appearances explicable by disturbing causes of which I have given you an example. The doctrine of Lucas has been forgotten by savants for a long time. If I have spoken to you about it, it is as a contemporaneous writer. Emile Zola has based upon it that great work of the Rougon-Macquart; he has sought thus to give it a scientific foundation; the unfortunate part is that before Zola had even commenced the publication of the first volume of that set of books other authoritative articles had already brought out the weak and inaccurate points of Lucas's theory.

A great English investigator, Sir Francis Galton, has employed, like Lucas, the direct method of observation in the study of acts of heredity. He has carried it to a very high degree of perfection. Thanks to some devoted cooperators, he has united a large number of genealogical trees in noting the physical, intellectual, and moral characteristics of all members in the family studied. A periodical work, " Biometrika," published these articles. The results were worked out in a special laboratory which is perpetuated under the name of the Sir Francis Galton Eugenic Laboratory. In applying to results thus accumulated the process of higher mathematics, Sir Galton and his pupils have established an empiric law, the formula of which, however, has changed. At first Galton showed that the two ancestors of the first generation (father and mother) control one-half in the heredity of a subject, each one being a quarter; then the four ancestors of the second generation (grandparents) are valued at a quarter in this heredity, one-sixth for each one; then the eight ancestors of the third generation (great-grandparents) come in for an eighth or a sixty-fourth for each one, etc. Subsequently,

Pearson, a pupil of Galton, saw that to agree with the reality, that formula was exact and conformed to observations only if there was made to intervene in each generation a corrective coefficient varying from the rest according to the subjects and characters considered, the corrective corresponding in total to the "innéite" of Lucas. On the whole, the "biometric method" of Galton and Pearson, in spite of the magnitude of their effort, led to such complicated formulas that they were unprofitable in practice. Besides, they gave simply formulas of a general term not at all applicable to a particular case considered independently of all other cases.

We are about to see that the formula of Mendel, which is much more simple, explains the results empirically stated by Galton and Pearson. The formulas of these last explain the proportion from the results given by the laws of Mendel applied to the whole of an extended population.

Mendel's laws are the foundation of the study of heredity to-day. But we should not forget that the most important of these laws had already been discovered by our compatriot, Naudin. Naudin, about the middle of the last century, had undertaken the study of the phenomena of hybridization, as Mendel had done, and had discovered the phenomenal principles which a little later attracted Mendel's attention, particularly the resemblance of some hybrids to one of its parents and the disassociation of characters in the descent. Naudin, who was deaf, and therefore isolated by his infirmity, did not know how to make the most of what his works merited, and it is to Mendel that the glory of establishing the remarkable laws which deservedly bear his name is given.

The fame of Mendel is of quite recent date; it has only been a few years that the learned world has known his name; and now it is already famous enough to have societies named for it ("Mendel societies") and a periodical (Mendel Journal) devoted exclusively to drawing from the discoveries of Mendel the inferences which they bear. This glory is tardy. It was in 1868 that Mendel published his discovery, but it was ignored, and it was not until 1900 that the Dutch naturalist de Vries brought out Mendel's laws, and it was not until then that the name of Mendel commenced to spread abroad.

Mendel was a monk in a convent of Moravia near Brünn. In his leisure hours he devoted himself to the study of natural history and cultivated a little garden where he hybridized sweet peas; it was in this way that he discovered the laws of hybridization which he published in a small local scientific paper, called "Bulletin de la Reunion Scientifique de Brünn," and they remained buried there. After a time, Mendel was appointed superior of the convent; his new occupations prevented him from continuing his work, and he died without knowledge of the fame which awaited him.

Mendel noticed the fact that when two varieties of plants differing in one characteristic only are crossed, the red or the white color of the flower, for example, all the seeds obtained therefrom produce in the first generation plants having red flowers only; if these hybrid red plants are crossed with them, 75 to 100 per cent of red-flowered plants and 25 to 100 per cent of plants with white flowers will be obtained. If the stalks of the white flowers are afterwards united, the red color would never appear; the stalks of the white flowers reappeared in definite proportions in the descent from the stems of the red flower united between them.

Mendel thought that the two characteristics, red coloring and white coloring, both exist in the hybrids of the first generation, but the red characteristic dominates the white and appears only when they exist side by side. If we call " R " the red characteristic and " B " the white characteristic, the formula for these hybrids is R(B), the parenthesis denoting that (B) is latent, because it is dominated. If a plant R(B) should be crossed with another plant R(B), the two characteristics would disassociate themselves in the pollen grains and in the ovules; half of the pollen grains contain only R and a half contain only B; the same with the ovules; the 50 per cent of pollen grains R now unite half with ovules R, half with ovules B; the fertilized ovules which result from the union have now as a formula half RR, or 25 per cent and half R(B), or again 25 per cent. In the same way the 50 per cent of pollen grains B unite half with ovules R and half with ovules B, and the fertilized ovules which result from this have for a formula the half R(B) and half BB, or 25 per cent R(B) and 25 per cent BB. The total is 25 RR, 50 R(B), and 25 BB. But the R(B) are red like the RR and can not be distinguished from them. There are now 75 per cent of red. Unite them and the reds still give a certain proportion of whites, which can be calculated for each generation under the formulas of the law of probabilities. Without entering into the detail of these formulas, understand that at the end of n generations of unions between reds resulting from the first crossing, the white being at each generation separated from the reproduction, we obtain n^2-1 stalks of red flowers for one stalk of white flowers. On the contrary, it is well understood that the stalks of white flowers BB united with each other never produce anything but the stalks of white flowers; they do not contain, either obviously or in any unseen way, any red element.

Such is Mendel's law. It is applicable not alone to the colors of plants, but to all other living beings, animals, and vegetables, to all simple characters, capable of producing two and two in varieties differing only by single characters. This law is found in the union of gray mice (dominant) with white mice (dominated), of normal

mice (dominant) with dancing mice (dominated), in the union of bay horses (dominating) and sorrel horses (dominated), in the union of a single-comb hen (dominating) with a double-comb hen (dominated), etc., and finally in the human species. In the human species verification of these laws can not, you understand, be carried so far. Nevertheless, it seems to be an established fact that light hair and blue eyes are dominated characters in the Mendel sense opposing the black hair and eyes, which are dominating characters; and one can, from that statement, infer from heredity the color of hair and eyes, some conclusions which are being verified almost constantly. In the same manner human albinos comport themselves the same as the white albino mice, and in their union their descendants obey the same laws. It is the same with many morphological peculiarities, which conduct themselves some after the manner of dominating characters and others after the manner of dominated characters. In family diseases the morbid character is inherited in certain diseases after the manner of dominating characteristics and in other diseases after the manner of dominated characters. In a word, Mendel's law is very general, from the highest to the lowest forms of life; it applies to a number of characters of varieties that may proceed from morphological, physiological, or pathological characters.

The discoveries of embryologists have made known how the mechanism of impregnation explains the Mendel law. By the combination of embryological discoveries and Mendel's discoveries we can state that the mystery of heredity has now ceased to be a mystery; nature has raised for us a new fold of her veil.

You know that all living beings are formed from the aggregation of very numerous small living elements called cells. Each cell is composed of a tiny mass of living matter, the protoplasm, in the center of a more highly organized part, the " noyau." All living beings sprang primitively from a single cell, egg, or ovule. The simplest of living beings remain all their lives formed of a single cell and reproduce themselves by simple division into two, from the cellular nucleus at first, and from the protoplasm mass later. Heredity among these lower forms of life is explained very naturally, since the two new beings are only, so to speak, a continuation of the primitive being.

With beings a little more complicated, the cellular egg undergoes successive divisions and produces a great number of cells, which remain agglomerate, and the ensemble reproduces the morphology peculiar to each species. A certain number of cells from the interior of the body are alone susceptible of giving birth to new beings; they constitute the eggs of the animal or the ovules of the vegetable. Although other cells are differentiated, these reproductive cells have

remained identical to the primitive reproducing cell, the successive divisions of which have led to the formation of the being in question. Here, again, the explanation of heredity is not difficult. The new reproductive cell is identical to the primitive cell. It is very natural that its evolution should be identical to that of the last, on one condition, however, that it finds, for its life and development, conditions identical to those which the primitive cell found. Now, these conditions exist for inferior beings; they live in the dense ocean, which has a composition very nearly stable. If, however, the conditions of development are artificially made to vary, either the embryo dies, which is the most frequent contingency, or descendants are obtained which differ from the parents by their irregularities, veritable stigmas of degeneracy (analogous to those of the descendants of human beings, the physicochemical composition of whose internal organs, of the blood, has been changed by sickness or intoxication, as the children of diseased or alcoholic parents, for example).

Upon the whole, heredity is easily explained, as well as deviation of heredity, as long as reproduction is a question of nonsexual beings, which inherit their characters from a single parent, and not from two at a time—the father and the mother.

As to the sexual reproduction of beings, the embryologist also gives us some very satisfactory explanations which accord very nearly with those which observations give us as to the manner of heredity transmission, and places in a vivid light in particular the facts observed by Mendel and his successors.

For sexually reproduced beings (we will speak, if you wish, only of animals, but it is also the same with vegetable life) the egg— that is, the primitive cell, the successive division of which will form the new being—is constructed from the intimate fusion of two cells, one of paternal, the other of maternal, origin, each one supplied from a kernel. The particular point is the constitution of those sexual cells from the kernel. Their ripening (that is, the moment from which they are susceptible of blending with the cell from the opposite sex to form the egg by that fusion) is marked by a curious phenomenon. One half of their kernel is expelled; the kernel divides itself into two with no special method; one of the halves reaches the pole of the cell and forms what is called the polar globule; then it is expelled. Each sexual element represents then a half cell, at least where the kernel is concerned; but it is the seed which is important in hereditary transmission. Here is proof of it: The sexual feminine cell is very large, containing in certain cases a thousand times more protoplasms than the masculine cell, which is very small and reduced almost to a seed, or, rather, a half seed. However, paternal heredity is not less power-

ful than maternal heredity; the origin from protoplasm carries very little weight from the standpoint of heredity; what really matters is the origin of the seed.

Since the seed is formed from two half seeds blended together, that explains how it bears in it two hereditary characters at the same time, as Mendel has shown. The Mendel formulas RR, RB, BB are, then, in exact accord with that which the microscope reveals to us of the embryological mechanism.

In showing you the Mendel laws we have supposed a simple case in which the parents differ only in a single character, the coloration, " R," and the albinism, " B." In reality there are a very great number of characters that make up the noyau, and each one is double in each cell, as much from the father as from the mother. In the cells from the father each double character is formed of an element proceeding from the paternal grandfather and of an element proceeding from the paternal grandmother, one of the two being latent. Then, from the expulsion of the polar globule one of the two elements of each character is expelled, and the expulsion bears by chance on the elements coming from the paternal grandfather on the elements coming from the paternal grandmother. The same happens in the mother's cells. Finally the cellular egg permits of a very great number of juxtaposition characters. The half comes from the father, half from the mother. and half between them are latent. But the proportions due to each of the grandparents are not fixed; they are given up to chance by the expulsion of the polar globule, and it is only when one considers the average results on a great number of subjects that the chances in an inverse sense balance each other and you arrive at the law of Galton; that is to say, one-sixteenth coming from each grandparent, one-sixty-fourth coming from each great-grandfather, etc. One can compare the juxtaposition in the descendant of the characters of paternal and maternal origin to a double mosaic, each one formed from little blocks of marble, added two by two; that which is under the corresponding block is the latent character, the other is the dominant character species.

In the same animal species the design of the mosaic remains always the same, but the matter of which each block is composed varies according to the individual. Two brothers resemble each other, because the blocks selected to compose their mosaic are taken from the two identical sources; but they resemble each other incompletely because the chance which provides for the distribution of the blocks proceeding from the grandparents and for the elimination of half of each gives changeable results; the half of the blocks are eliminated, and it is not always the same ones which are eliminated. It is, however, a case where the resemblance between the two brothers is strik-

ing. It is the case of twin brothers called "univitellins." There are twins called "bivitellins," who owe their origin to the development of two eggs side by side; these do not resemble each other more than two ordinary brothers. But there are also twins called "univitellins," who owe their origin to the fact that a single egg is primitively cut in two and each half has developed a complete being. Then the identity is complete, and there is no more striking demonstration of the power of heredity than to see these two beings, who are sometimes brought up under different conditions, who choose different careers, and who, nevertheless, resemble each other so closely that their families are apt to confound one with the other even up to extreme old age. In these cases the mosaic is not only made on the same design (as is the case with all beings of the same species), it is not only formed from blocks taken at random, one half each from two different sets and distributed at random, in two different stages, but it is the same choice—I should say the same expulsion of the polar globule—which has presided at the distribution of the blocks. It is, as it were, a perfect replica of the same mosaic. You see, ladies, how the knowledge of these laws and the mechanism of heredity explains certain facts up to this time considered as unaccountable curiosities.

It is not alone in the interest of curiosity to understand the laws of heredity. I have told you that certain diseases—family diseases—are obedient to these laws in their transmission; that the physical, intellectual, and moral faculties are inherited in the same way. The knowledge of these laws permits the avoidance of certain dangers that could result from certain unions. Up to the present time doctors are contented with dissuading in a general and vague way from a union with families where one of its members might have shown a physical, psychical, or pathological defect (but what family is entirely exempt from it), and to proscribe all consanguineous unions. Henceforth the prohibitions should be more precise and more clearly stated, and, on the other hand, permits which would have terrified the ancients should be given without any hesitation. Studies of this kind are but just beginning. Some influential societies have been formed in other countries for the study of this subject; in England and the United States they have become of great importance. In France La Société Française d'Eugénique was very recently organized. The results already obtained from these efforts are most encouraging.

In closing this lecture I wish to call special attention to certain conclusions of practical importance.

First. In microbic diseases, and especially in tuberculosis, heredity is far from being fatal. One can hardly say that children of tuberculous parents inherit from a soil favorable to the development

of the bacillus. If care be taken to avoid contact with persons who are suffering from the disease, they will have a good chance to escape the terrible scourge.

Second. Aside from the diseases from microbes, there are other disorders, notably hereditary, known as family diseases. And here, also, up to a certain point, the perpetuation of the disease may be avoided by binding oneself to certain strict rules. Each of these diseases has its own method of hereditary propagation, and knowledge of this method indicates the unions which the laws of heredity prohibit.

Third. Physical, intellectual, and moral faculties are likewise inherited under the same well-defined laws. But they are not fixed in the descent, as when their heredity is bilateral.

Fourth. Great efforts are being made at this time to perfect and extend the studies relating to heredity; societies and eugenic laboratories are being founded. We can hope that these efforts will show us the way to secure amelioration for the generations to come, and a lessening of congenital defects, the frequency of which weighs so heavily upon poor humanity.

HABITS OF FIDDLER CRABS.

By A. S. Pearse,

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Fiddler crabs are of unusual interest on account of their striking sexual dimorphism. The male bears an enormous claw on one side of the body which is in striking contrast to its feeble mate on the opposite side, while the female has two little chelipeds like the small claw of the male. Since the time of Darwin (1874) these crustaceans have been believed to furnish evidence of sexual selection. The great claw and bright coloration of the male differ markedly from the comparatively dull dress and small bilaterally symmetrical chelipeds of the female. Alcock (1892, 1900, 1902) is convinced that (1900, p. 351):

In one species, at any rate (*Gelasimus annulipes*), the males, which are greatly in excess of the females, use the big and beautifully colored cheliped not only for fighting with each other, but also for " calling " the females.

FIG. 1.—UCA PUGNAX, MALES AND FEMALES.   Woods Hole, Mass.

According to the same writer (1892), Milne-Edwards describes a South American species, in which the male and female lived together in a single burrow, the former closing the domicile with his large chela. But Calman (1911) is apparently not convinced that the uses of the great chela of male fiddlers has been demonstrated, for he says (p. 106):

What the precise use of this enormous claw may be does not seem to be quite certainly known. It is said to be used as a weapon by the males in fighting with one another, but it seems too clumsy to be very efficient for this purpose. It is often brilliantly colored, and has been supposed to be a sexual adornment.

The writer was first attracted to the study of the fiddlers by the great colonies of gaudy species which swarm along the beaches of the

coves and estuaries of Manila Bay. Later experiments were conducted on the coast of Massachusetts, and these were supplemented by observations in the estuaries and mangrove swamps near Santa Marta, Colombia. Altogether 13 species have been watched with considerable care, and their behavior has been similar in all essential respects.

GENERAL HABITS.

Fiddler crabs are diurnal. Other crustaceans (*Thalassina, Cardiosoma*) which inhabit the ocean beaches with them may be found at night if their haunts are visited, and they often stupidly sit in great numbers, dazed by the glare of a light, but fiddlers retire when the sun goes down and remain in the bottoms of their burrows until morning. Fiddlers are said to be sometimes active on moonlight nights, but, at any rate, a certain amount of light is necessary to bring them from their burrows. Prof. Holmes (1908) found that *Uca pugnax* was strongly positively phototropic when tested under laboratory conditions.

Different species of fiddlers often select the exact habitat, in which they are accustomed to dwell with great nicety. On the coast of Massachusetts two species live on the same beaches, but *Uca pugnax* usually digs its holes in mud, while *U. pugilator* prefers sand. In the Philippines this specificity of habitat gives rise to fiddler zones along the populous margins of the *esteros*:[1] (1) High along the edge of the shore *Uca forcipata* is found; (2) this zone grades into one of *U. rathbunae* just below, and is followed by (3) another in the softer mud of the deeper parts of the estero, peopled by *U. marionis* and *U. marionis nitida*. On the shores of Colombia *U. mordax* is found in the clay near the mouths of rivers, and is also abundant with *U. minax* in the soft mud among the roots in mangrove swamps.

In addition to their diurnal habits and discrimination in the selection of sites for their burrows, fiddlers exhibit a third striking peculiarity in their reactions to tidal changes. Countless individuals are seen on the mud flats at low tide, and active feeding is carried on then. The same is true when the tide is rising or falling. When the ocean threatens to cover the mouth of a burrow, however, a plug of mud is carried to the hole and drawn down after the owner in such a way as to shut him inside. During a period of high tides burrows in low situations often remain closed for several days; during low tides those on higher ground may be left open day after day, though the flats dry out to such an extent that crabs can not feed easily and remain at the bottoms of their burrows.

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[1] Estuaries.

BURROWS.

In excavating her burrow a female fiddler digs with the walking legs of either side. After a piece of mud has been pried loose by working under it with the legs, it is carried to the mouth of the hole
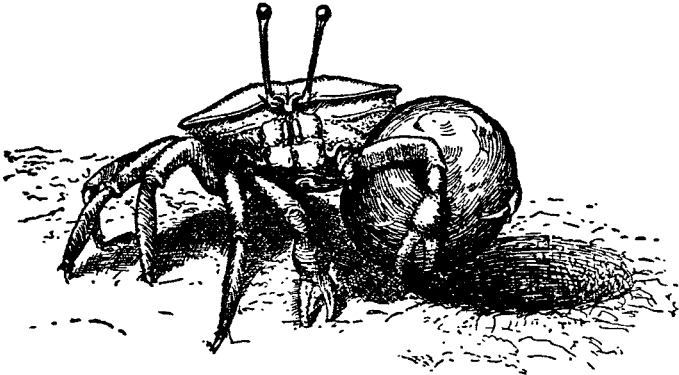
FIG. 2.—UCA RATHBUNAE CARRYING A LOAD FROM HER BURROW.
Drawn by Tom Jones from a photograph.

and deposited outside (fig. 2). The males do not use the big chela in digging or in carrying dirt, but work much like the females. They gouge out mud with the walking legs and usually carry it with
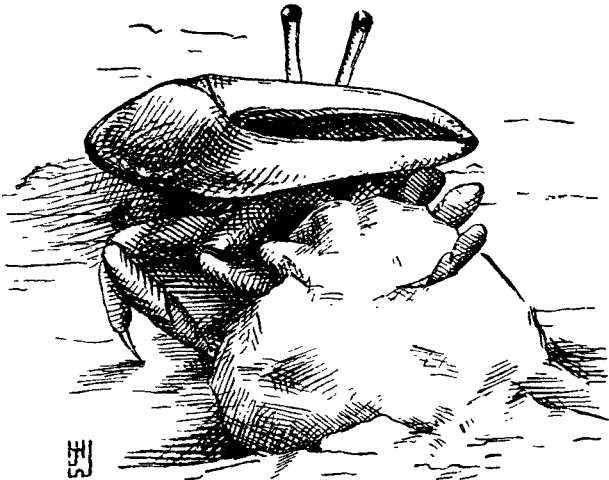
FIG. 3.—UCA RATHBUNAE. MALE GOUGING A PLUG FROM THE MUD WITH
WHICH TO CLOSE HIS BURROW.
Drawn by Hattie Wakeman from a photograph.

the first three legs on the side of the body bearing the small chela. Rarely they may be seen awkwardly carrying a load in the two walking legs just behind the great chela.

Usually the excavated dirt is carried to a particular spot several inches from the mouth of the burrow and placed in a neat pile. The speed of excavation varies considerably, but the average time between loads is usually from half a minute to three minutes when a crab is working steadily.
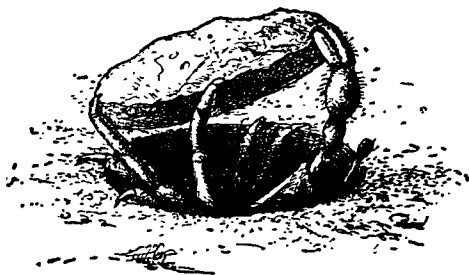
FIG. 4.—A FIDDLER CRAB CLOSING ITS BURROW BY PULLING DOWN A DISK OF MUD.
Drawn by Tom Jones.

As has been stated, nearly every burrow is closed by means of a temporary earthern doorway when the tide comes in. Often the mouth of a hole is prepared by bringing in a bit or two of dirt from outside or by carrying up some mud from below. Such masses are plastered around the mouth of the burrow and smoothed over to make the opening more nearly circular. When all is ready the crab goes a little way off and secures a disk of stiff mud (fig. 3) which he carries back to his hole. This plug he draws down in such a way that the mouth of the burrow is neatly and completely closed (fig. 4). When the mud on the beach is too soft to make a suitable plug, mud is pushed up from inside the burrow so as to close it or the legs are protruded a little and the opening nearly closed by pulling at the soft mud (fig. 5) until the small remaining aperture can be easily plugged by pushing up material from below. When a fiddler wishes to open a burrow that has been sealed, he usually pulls the door down into the hole, where it is left.
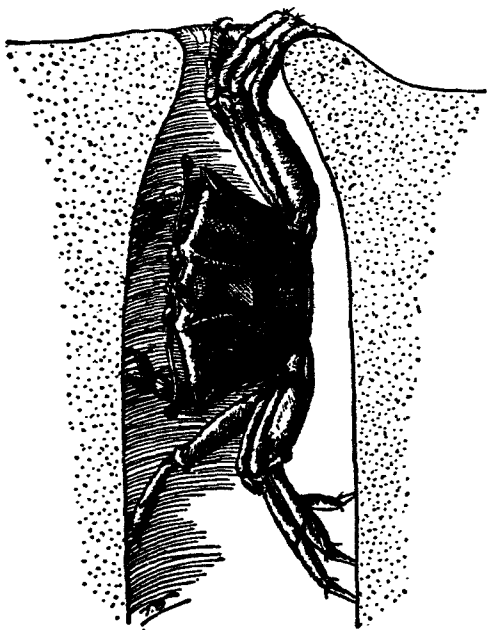
FIG. 5.—SHOWING HOW A BURROW IS CLOSED FROM INSIDE.
Drawn by Tom Jones.

Fiddlers seem to feel that the necessity for having their burrows closed when the tide comes in is very urgent. Once in Massachusetts I pulled up all the grass on a thickly populated area about 6 feet

square and chased all the crabs into their holes. Then I sat in front of this open space while the tide covered the mouths of the burrows. Though the crabs were timid and apparently feared me, several of them rushed out when the water came near and, after hastily grabbing one or more pellets of mud, plugged their holes.

Fiddlers are very cleanly in their habits, and may often be seen scraping themselves with the small chelipeds or with the walking legs when dirt has accumulated on any part of the body. They are particularly careful of the eyes and eyestalks, and these organs are often folded into their sockets to be cleaned. Mud or débris is not allowed to accumulate about the mouths of the burrows. Fiddlers are often seen moving such matter to some little distance, where it is cast aside or pushed down the holes of other crabs.

Crabs of either sex move sideways when entering the burrow, and the males usually have the large chela uppermost as they disappear. The holes are, as a rule, of uniform diameter, though they may be slightly enlarged at the bottom, and often turn so as to take a horizontal direction. They vary in depth from about 16 to 75 centimeters, and usually have water standing in the deeper parts, even when the tide is out.

PLACE ASSOCIATION.

A fiddler usually does not wander more than a meter or two from his hole, and is ever ready to dart into it at the slightest provocation. Occasionally, however, a crab roves as much as 12 meters from his home and returns. Once in the Philippines a *Uca marionis nitida* left its burrow and dug a new one 4.5 meters away; another individual moved his dwelling place 2.4 meters; but such cases were unusual. Most crabs showed a strong preference for a particular locality. Place association is also manifest when fiddlers carry mud from their burrows. Successive loads are not cast aside anywhere, but are usually carried to a particular spot and laid in a pile.

A number of crabs were snared and moved various distances from their holes to see if they would return. If the space was less than 2 meters, they usually came back at once. At greater distances some crabs dug new holes and reestablished themselves, even though they were in plain sight of their old homes; others tried to return home, and were not able to do so. It is by no means easy for a strange fiddler to make his way through a densely populated portion of a colony. He is set upon by every crab whose hole he approaches, and may lose his claw or even his life in such an engagement. An individual put down in strange surroundings acts shy and timid. Notwithstanding the difficulties, however, some crabs returned after several days to the hole they had previously occupied. One individual was moved 6 meters, and returned after 23 days to within 30 centimeters of his old home, which had been filled up by the tides in the meantime.

FEEDING.

Female fiddler crabs feed by scooping up mud with the hairy spoonlike fingers of the chelipeds and carrying it to the mouth, the two hands alternating rapidly. The males use only the small cheliped when feeding. The feeding appendages are well suited for the work they have to do. Their fingers are flattened and hollowed in such a way that they form admirable dredges for carrying mud to the mouth. Crabs seldom try to feed when the flats are dry and are most active when the tide is falling. The mouth parts sort over the mud which is scooped up and a mass of rejected material collects below them to drip down or be wiped away now and then by a cheliped.
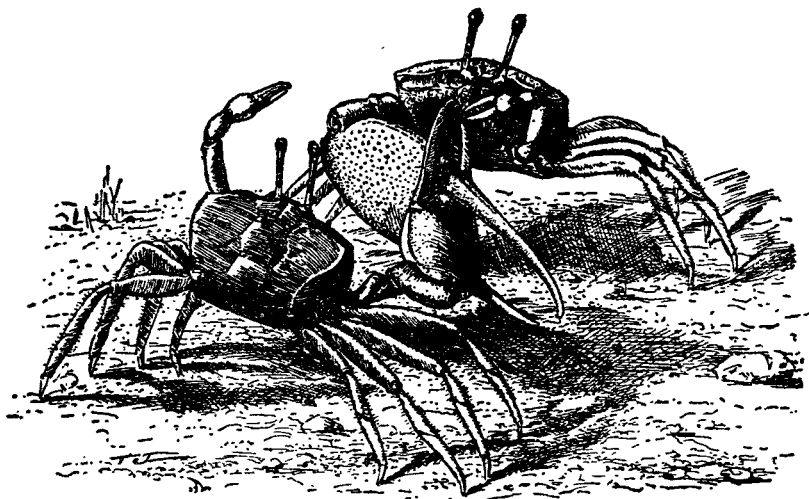
FIG. 6.—MALE FIDDLERS FIGHTING.
Drawn by Tom Jones.

An examination of the stomachs of several fiddlers showed that the diet is largely vegetarian. The food consists mostly of small algæ sifted from the mud. But fiddlers, like most crabs, will eat nearly anything that is cast upon the beach—dead fish, dead crabs, plants, etc.

DEFENSE AND OFFENSE.

A fiddler crab lives on a beach crowded among vast numbers of his fellows, but his intercourse with them shows no development of social instincts. He has selected his most suitable habitat, and the fact that he is surrounded by hundreds or thousands of his own kind is more or less incidental. Each fiddler searches the mud around his hole for food, and "his hand is against every man." He is ever ready

to dart into his burrow, and if danger threatens he quickly retreats to this refuge. If one of his fellows encroaches on his domain, however, he rushes forth and enters into fierce combat. Each crab makes his hole the center from which his activities are conducted, and he treats the approach of any intruder as an unfriendly act.

Though combats between two males are most frequent, males sometimes fight with females, and members of the weaker sex not infrequently struggle with each other. If two males that differ markedly in size fight, the larger combatant usually takes little interest in the fight and soon makes off, even though he may be hotly pursued by his smaller antagonist. When a smaller fiddler trespasses on a larger crab's territory, however, he is soon chased away. The most spirited combats are between males of the same species.

In fighting (fig. 6), the males face each other and often dance about excitedly, at the same time frantically waving the small chela.
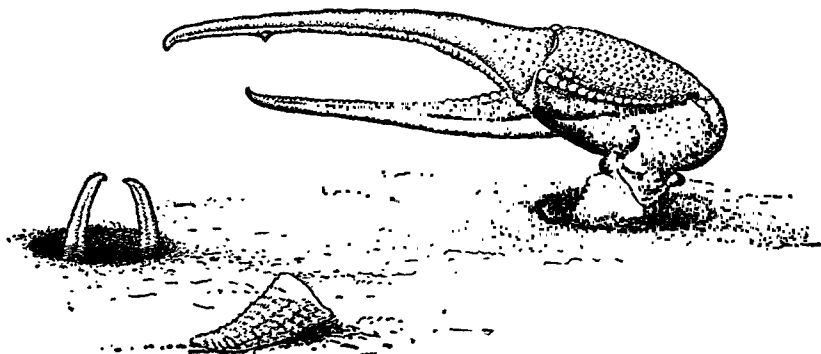
FIG. 7.—FIDDLERS DEFENDING THEIR BURROWS.
Drawn by Tom Jones.

The large chelæ are locked together, like two men shaking hands, and each contestant attempts to break off his opponent's claw by a a sudden wrench. The strain is so great that when one of the fighters loosens his hold rather than lose his claw, he is often thrown backward into the air, sometimes as much as a meter. The writer has never seen the great chela used as a club in fighting, as Alcock (1892, p. 416) maintains, but it often serves as a shield to ward off a thrust. If a male gets the worst of an encounter, he frequently retreats into his burrow and guards it by extending his claw from the opening. (Fig. 7.) Sometimes one male catches another napping and enters his burrow. In such cases the owner waits nervously about until the intruder comes out and then chases him away, or he boldly goes down after the intruder with his large chela extended before him and usually emerges soon after followed by the intruder.

PLAY.

Some of the activities of fiddlers are like those displayed by higher animals while at play. Crabs frequently dart about without a serious purpose, and are sometimes downright mischievous. On one occasion a male was half-heartedly pursuing a female. She went to her burrow, secured a plug nearby, and shut herself in. The male then came directly to the burrow, seized the plug, and cast it to one side. The female was just emerging from her burrow when the writer ended the episode by frightening the participants by a sudden movement. Another time two males of medium size were seen running about for perhaps half an hour over an area about 12 meters in diameter. They kept close together and acted like two mischievous sailors ashore. The tide was coming in rapidly, and in their rambles the pair came to a place where a large, slow-moving crab was carrying a plug to close his burrow. The pair waited until the plug had been pulled down, then one of them went to the hole and removed it; as the outraged owner emerged they scuttled away. To all appearances activities like those just described were carried out in a spirit of " sport."

MATING.

During the mating season a fiddler-crab colony is an interesting place. If a female walks across the mud every male stands at the mouth of his hole and waves his big claw frantically up and down, often accentuating such movements by squatting and stretching with his walking legs. (Fig. 8.) If a female approaches he makes every effort to induce her to enter his burrow, frequently dancing or posturing before her.

A courtship will be described, which was observed at North Falmouth, Mass., July 11, 1912. The male waved, and at 12.17 p. m. the object of his attention approached and went part way into his burrow. He rushed up and tried to push her in, but she resisted. He then retired 3 inches and stood motionless for three minutes with his claw outstretched in front, then sneaked up and again tried to push his prospective mate into the burrow. She again resisted, he retired, and both were quiet for two minutes. The male then approached cautiously and stood motionless with upraised chela close to the female for three and a half minutes; then he again attempted to push her down, but without success. He then raised his claw and standing high on his legs assumed a statuesque pose which he held for 10 minutes (I took his picture, fig. 9). The female, meanwhile, fed a little, moved away a couple of inches, then went part way down the hole. When the male again approached, she dodged, but came

back and entered the hole. The male stood over her for more than a minute. She dodged away, again came back, and the male stood over her again. At 12.42 he went to one side of the burrow, she to the other; and they stood thus for four minutes. At 12.46 the female moved away an inch, at 12.52 the male dodged quickly into his burrow, and the female went up to him, but a minute later she moved away several feet and finally went elsewhere. The male,
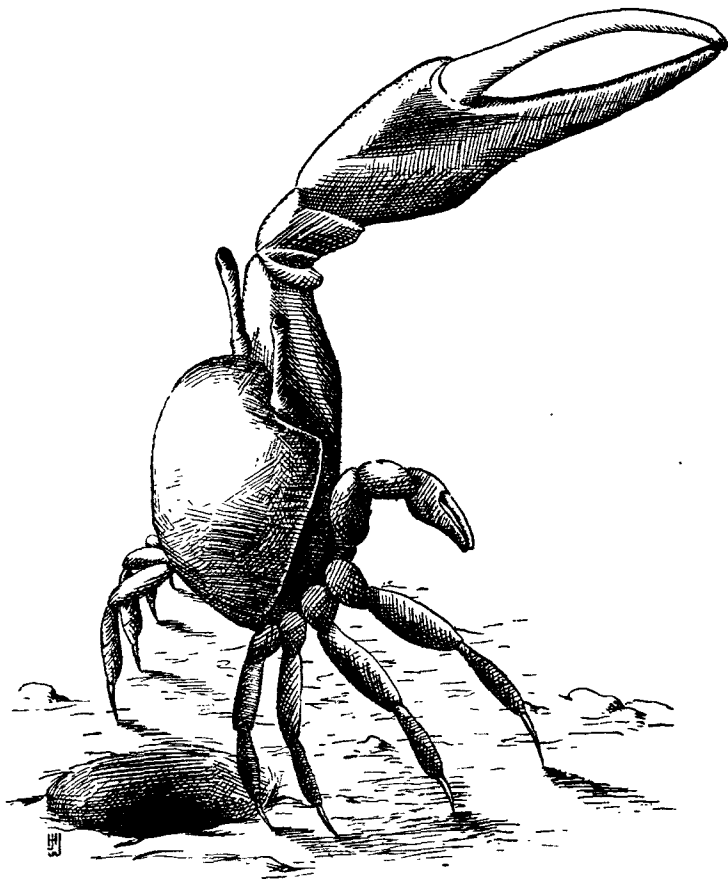
FIG. 8.—UCA PUGILATOR. MALE WAVING HIS GREAT CLAW TO ATTRACT THE ATTENTION OF A FEMALE. Drawn by Hattie Wakeman from a photograph at West Falmouth, Mass.

however, was soon consoled, for at 1.02 p. m., he was standing at the mouth of his hole waving at another female.

The male made no attempt to use his great chela in holding the female. After his first rush he had every appearance of proceeding with great caution—as if he feared a too arduous wooing might cause his prospective mate to leave. After every repulse he retired a little way and displayed his charms for a time before making another

advance. Apparently he was attempting, as Chidester (1912) says, to "demonstrate his maleness." In the Philippines crabs were often seen standing motionless with outstretched claw for as much as 20 minutes. (Fig. 10.) Perhaps such individuals were looking for a mate.

FIG. 9.—UCA PUGILATOR. MALE IN COURTING ATTITUDE BEFORE A FEMALE.
Drawn by Hattie Wakeman from a photograph taken at West Falmouth, Mass., July 11, 1912.

Probably fiddlers copulate in the burrows of the males, but they have never been seen to do so. Experiments have been conducted in the laboratory, however, in which the mating activities were observed. Jelly glasses were filled with clean water to a depth of about an inch; a male and female were then placed together in each. Sev-
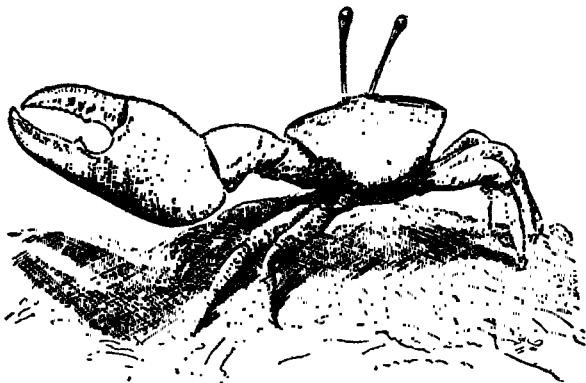
FIG. 10.—UCA FORCIPATA STANDING AT ATTENTION.
Drawn by Tom Jones from a photograph.

eral copulations were observed under such conditions. In no case did a male use his great chela in manipulating or holding the female, and that organ was not used as a "nuptial couch," as some have supposed it would be. A figure has been published elsewhere (Pearse, 1914), which shows the position assumed during copulation.

GENERAL CONSIDERATIONS.

Fiddlers treat other animals with suspicion. Any large moving object causes them to retreat at once to their burrows, although they soon emerge again if the object is not near at hand. Most crabs retreat into their holes when a man approaches within 15 meters, but if one is careful not to make any quick movements he may sit apparently unnoticed within a couple of yards of an active fiddler for hours at a time. Large adult crabs like *Sesarma bidens* are avoided, but small crustaceans of any species are at once attacked. Any strange animal, however small, is avoided; the writer once saw a small hermit crab, by moving quickly along the edge of the rising tide, cause every fiddler near to run for its hole. The fiddler's burrow furnishes a retreat from many enemies, and his speedy reaction toward it in response to all movements in his field of vision would help protect him from the herons, snakes, skinks, frogs, toads, and fishes that commonly hunt along the shores of the estuaries.

In reacting to its surroundings a fiddler crab apparently uses its senses of sight and touch most, although the recognition of chemical substances may be important in securing and selecting food. The eyes are very quick to note any movement in the landscape; they are held straight upward, except when their stalks are being cleaned or when a crab is entering a burrow. Feeding probably depends mostly upon the tactile and chemical senses, for the usual position of the eyes is such that the small chelæ can not be seen as they pass food to the mouth. Such loud noises as whistling, hand clapping, gunshots, and locomotive whistles produced no apparent reaction from the fiddlers, nor did the stridulation of the large decapod, *Thalassina anomala* (Herbst), that builds its burrows among them in the Philippines.

Although fiddler crabs live together in enormous colonies, they show no cooperation with one another, nor do they manifest any tendency toward such communal existence as that displayed by some other arthropods; for example, ants, bees, wasps, and termites. In this they agree with other crustaceans, for, though the animals of this class exhibit an endless variety of structural adaptations suited to various habitats and modes of life, none of them has taken advantage of the opportunities offered by a cooperative communal association among members of the same species (except in some instances in which the male is intimately associated with the female). Although the females of many species carry their eggs and newly hatched young for a time, the association of the young with their mother is nominal, for she never feeds or cares for them. The struggle for existence is nowhere more apparent than in the midst of a fiddler crab colony. Each individual jealously guards the area about

his own burrow and immediately attacks any invader of this territory. His pugnacity is ever ready to show itself against his fellows that swarm about him and against numerous competitors of other kinds that also seek to eke out an existence from the area he has chosen for his own.

The fiddler's chief competitors for the food on the beaches are other species of crabs, various smaller animals such as snails and worms, and some larger animals like fishes and birds. In addition to honest competition the fiddler must reckon with some larger animals, which seek not his food but himself. Among these the raccoons, herons, snakes, skinks, frogs, toads, and fishes are most important.

The behavior of the fiddler is admirably suited to enable him to gain a livelihood and at the same time escape injury or death from his enemies. His aggressive attitude toward members of his own genus and toward other crabs of similar size keeps enough space clear about his burrow to enable him to sift his simple diet from the mud in comparative safety. Furthermore, the way is thus left clear for retreat to his burrow if danger threatens, and the fiddler is not slow in dodging into his hole as soon as any strange or threatening object moves within his field of vision. His burrow is the center of all his activities, and his association for the place where it is situated is very strong. Fiddlers are protected from night prowlers by their diurnal habits, and they escape the fishes and snakes that hunt at the edge of the advancing tide by closing the openings of their burrows when the water threatens to inundate them.

Although the majority of the reactions of fiddler crabs are stereotyped and appear to be instinctive, yet they are open to some modification. The daily life of a fiddler is more or less of a routine—to dig a burrow, to seek food as long as the territory about his burrow is clear, to attack small aggressors, to retreat from large enemies, to plug the burrow when the tide comes in, to open it when the water recedes, to retire during darkness, and to mate at the proper season. These are his ordinary activities, and they depend largely upon unvaried reactions. Some instincts are so strong that, although usually advantageous, they may be harmful; for example, place association and instinct to retire into her hole was strong enough to cause a certain crab to remain for some time in danger when the burrow could not be entered and she might have escaped by running away. Nevertheless, a fiddler shows some ability to modify his reactions to suit circumstances, such as departing from his usual method of carrying mud from his burrow, using different ways to plug the burrow, and in some other activities.

A fiddler crab is able to establish a place association for a certain locality and to retain it for as long as three weeks. Some activities

might be interpreted as manifestations of a desire to play. The instinct to fight males of his own species and size is very strong in a fiddler, yet this instinct is more than a " fighting reflex," for he is slow to resent an attack by a smaller male.

Concerning the structural differences between the sexes, it may be affirmed that the great chela of the male does not serve for burrowing or feeding. In fact, it is rather a disadvantage in either of these activities. The great chela closes the burrow inasmuch as it fills the opening as a weapon of offense, but is not used as a lid or stopper. It is of no advantage during actual mating, but unquestionably serves as a signal which is waved to attract the attention of females. The great chela is of undoubted use to the male in combats with his fellows and in defending himself from other enemies. In this respect it is comparable to the secondary sexual characters of some other male animals, such as the stag's antlers, the cock's spurs, and the tusks of the walrus. Among higher animals in which the males possess such aggressive organs, however, the females are protected and cared for to some extent, but nothing of this sort is known among decapod crustaceans with secondary sexual adaptations (*Uca*, *Alpheus*, and others). Thus, although many of the crustacea have two adaptations which might fit them for colonial life—through the mother carrying her eggs and young for a time, thus having opportunity to start a colony with them, and through the aggressive adaptations of the males, which might enable stronger individuals of that sex to gather a number of females about them—their instincts have prevented them from developing it.

Alcock (1892) believes " no one can doubt that the claw of a male has become conspicuous and beautiful in order to attract the female," and that " it is used as a signal to charm and allure the females." Though there are perhaps such minor objections to such a statement of the case, it is certain that male fiddlers do wave their claws, dance, and pose in the presence of females. It must be admitted, also, that, though bright colors occur on other parts of the bodies of both sexes, the great chela are always colored so that it is conspicuous. At present it is not possible to state just what part specific colors may play in attracting the females of particular species. The problem should be studied during the active mating season with special reference to color. By observing the coloration of males actually chosen, by painting the chelæ of rejected suitors, by " waving " colored mock chelæ, or by other tests, a definite conclusion could doubtless be reached. Until such experiments have been made it can hardly be affirmed that fiddler crabs show the operation of sexual selection through color discrimination.

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THE ABALONES OF CALIFORNIA.[1]

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[With 10 plates.]

The abalone belongs to a family of marine snails, the Haliotidæ, which has many representatives in the waters about Africa, India, Japan, and the neighboring islands. Six species and one variety have been described from the Pacific coast of North America, but none from the Atlantic coast. Under the name of ormers, sea-ears, or ear-shells, this gastropod occurs on the coast of France and among the Channel Islands, but the species are most abundant in tropical and semitropical regions.

The abalone is of importance because of its beautiful shell, polished as an ornament, or manufactured into many kinds of novelties and jewelry. Gleaming with the iridescence of the rainbow and the aurora this lovely shell is fit to be the chalice of Eos. Pearls may be secreted around foreign particles accidentally, or designedly, introduced between the mantle and the nacreous layer of the shell. The mollusk *Pholadidea* may bore through the shell and cause the formation of the blister-pearl, or we may bring about the same result by inserting a prepared form. Then the meat, either fresh or dried, is of much food value.

In the commercial fishery of abalones, one or more crews are employed, generally made up of Japanese, but sometimes of Chinese or American fishermen. The boat containing a crew is either rowed, or driven by motor, from the camp to the fishing grounds. The crew consists of the diver and his 6 assistants. When over the right bottom the diver is clothed with his suit, the helmet screwed upon the brass collar, the heavy lead breast and back weights adjusted, and the air pump manned. One man takes the diver's signal rope, another the hose from the air pump, and the diver, with a net attached to a rope and his shucking chisel in hand, is assisted over the side, climbs down the short ladder, and drops through the water to the bottom.

If he finds the abalones plentiful, work is continued in depths of from 20 to 65 feet, in four-hour shifts. The man on the boat with the signal rope in hand follows the course of the diver by the constant stream of air bubbles rising to the surface. When the kelp is thick one man has a knife on a long pole with which he cuts the seaweed and keeps the air tube clear.

The diver finds it an easy task to detach the abalone from the rock if he pushes the shucking chisel under the expanded foot before the animal is alarmed. If, however, the diver hesitates and the abalone contracts its muscular foot a powerful pressure is exerted. One or two cases have been reported of the drowning of Chinese fishermen who have had their hands caught by the abalone and thus held until overcome by the rising tide. The diver secures a net full of abalones, gives the signal, and the mollusks are hoisted aboard and stowed below. The net, filled with about 50 green and corrugated abalones may be hauled up every six or seven minutes. During his shift below the diver gathers from 30 to 40 basketfuls, each containing 100 pounds of meat and shell, or altogether 1½ to 2 tons.

At Santa Catalina Island, and later at San Clemente Island, in company with a Japanese diver, I donned a diving dress for submarine exploration. On one occasion the assistant failed to tighten the waist belt which is designed to keep the air in the upper part of the diving dress. The men at the pump worked with especial assiduity, and as I dropped off the ladder the inflated rubber trousers turned my feet uppermost. Head down I went through 65 feet of water, and then, not in a position for quiet reflection, remained some moments before the Japanese assistants concluded that my signals were not being made just for the fun of it. After being pulled to the surface, reversed and relieved of inferior inflation, a successful descent was made. The submarine journey is a wonderful experience. The bottom of the sea seems made of grains of gold and silver, shimmering in the penetrating sunlight. Upon the face of a precipice, large specimens of the green and corrugated abalones rest. The shell of each is covered with a luxuriant growth of algæ, hydroids, and tentacled tube worms, which mask the creature from its enemies. All about are large fish which swim close and peer through the glass window of the helmet. An enormous sting-ray indifferently floats by. One has a fellow feeling with these unfrighted denizens of the deep in the fascination of observing their behavior under natural conditions.

In gathering abalones sometimes a crew is composed of six divers, who work without suits up to a depth of 20 feet, and some of them remain under water for as long as two minutes. These expert swimmers protect their eyes with glasses and wear cotton in their ears. They pry off the abalones with a shucking chisel, often filling their

arms on the way to the boat. Every two hours they return to the launch to be warmed at the fire. It takes the united efforts of these six men to equal the catch of one diver in a suit.

The abalone has a well-developed head and a powerful, adhesive, creeping foot. The shell is flattened, and the spire, which is such a prominent conical structure in most snail shells, is depressed and inconspicuous in this form. The last greatly enlarged whorl contains the body, especially characterized by the enormous columellar muscle, whose fibers run from their origin upon the muscle scar, or center of the shell, into the foot. Numerous contractile tentacles arise from the fringed epipodial fold, or ruff, around the base of the foot. The gills, alimentary system, reproductive glands, kidneys, heart, and blood vessels and the pallial and visceral sections of the nervous system lie to the left of and behind the columellar muscle and foot. From the mouth cavity the gullet leads backward to the enlarged stomach, which is divided into two compartments, and receives the digestive juices from the large digestive gland at the hind end of the body. Two pairs of salivary glands pour their secretions into the buccal cavity. The intestine runs anteriorly to the side of the head, there turns on itself, and proceeds back to the stomach, where it again goes forward, passing through the ventricle of the heart, to terminate in the anus, which opens into the gill cavity. The shell is perforated toward the left by a series of openings lying above a slit in the mantle fold leading into the gill cavity, whence issues a stream bearing the excrement, respiratory, and excretory wastes. Three tentacular processes from the edges of the mantle cleft project through these holes. As the animal grows the apertures in the shell behind the respiratory cavity are closed up and new ones are formed at the anterior edge.

The head terminates in a short snout, on either side of which is a somewhat slender olfactory tentacle, and slightly lateral to this a shorter and broader optic tentacle. Two elongated ganglia lying above the mouth cavity may be called the brain, because they form the center for nerves from the eyes, olfactory tentacles, snout, lips, and other parts of the head. The eye is a simple cup-shaped depression of the epithelium on the end of the tentacle. The cup is filled with a gelatinous lens and it has clear and pigmented retinal cells connected with fibrils from the optic nerve. The shadow of a hand passing over the abalone in an aquarium causes the animal to contract the head end of the body. Hence the abalone differentiates various intensities of light, and thus possesses a primitive sense of sight. The contractile tentacles running out in every direction from the ruff are end organs of touch. Each has a nerve connected with either the right or left pedal cord. These two centers of innervation run through the middle of the foot for the greater part of its length and are connected by cross fibers. They not only receive stimuli

from the sense organs of the ruff, but govern the multitude of muscle fibers which form the foot.

Scattered all over the exposed parts of the body are long spindle-shaped cells which may respond to such mechanical and chemical stimuli as to make of them indefinite end organs of touch and smell. In the floor of the mantle cavity a water-testing sense organ, the osphradium, extends along the base of each gill. The cells of this simple end-organ are chemically stimulated in such manner that the abalone has sensations of smell, warning it to shut off the incurrent water when foul or containing some poisonous matter.

If a piece of kelp is held motionless in front of the body, the animal soon responds by reaching out the cleft anterior portion of the foot. These fingerlike processes grasp the seaweed and pull it back beneath the mouth and foot, where it is firmly held. Cells in the mucous lining of the mouth cavity are stimulated so that the animal gets the sensation of taste. Covering the tongue is a long horny, filelike structure, the radula, with many thousands of chitinous teeth symmetrically arranged in transverse and longitudinal rows. The teeth are pointed backward, and as the tongue is thrust out and drawn in the radula rasps a hole in the succulent kelp, carrying the fragments of food to the opening of the gullet. Two chitinous jaws, one at either side within the mouth, but united in the midline, serve as scrapers to hold back in the mouth cavity the particles of food adhering to the radula. This method of feeding abalones individually by hand is of importance in easily caring for the animals in confinement in aquaria or in inclosed pools or live boxes in marine farming.

As food the abalone is one of the best of our marine mollusks. Detached from the shell, the visceral mass and mantle fringe are trimmed off from the large central muscle, which is then cut transversely into slices. These small steaks, when beaten four or five times with the flat side of a meat cleaver and then fried in butter, are tender and delicious. The meat is also equally delectable when served as a chowder or minced. Besides supplying the local market the mollusks may be shipped across the continent, for when individuals are placed one on top of the other, in a sort of a living nest, they will survive for as long as six days without water, feeding upon the organisms and organic slime covering the shells upon which they rest. While the American market is not sufficiently developed to create an active demand for fresh abalones yet in a dried state many are shipped to China. After being gathered from the rocks by the diver and taken into camp, the shells are removed and the abalones thrown into vats of salt water and left for two or three days. In this manner, the pigmented mantle fringe is removed and the meat preserved. The abalones are next washed in large tubs by means of wooden paddles and then cooked for one half hour in water almost

at the boiling temperature not only for sterilization, but to give the meat the desired rounded shape. With dipnets the Japanese workmen remove the abalones to baskets and carry them to the drying frames, where they are laid out in trays in the sunshine. After four or five days, or longer, if the temperature falls, the partly dried abalones are cooked in water for the second time for one hour. Next they are smoked in charcoal smoke for from 12 to 24 hours, and then for the third time placed in boiling water mainly for rinsing. Now they are dried for a period of six weeks and after a final cleansing bath in luke-warm water made ready for shipment. During the process of drying the meat loses nine-tenths of its original weight. While hard and tough, like dried beef, it may be sliced with a sharp knife and eaten with relish. When dried the meat brings from 12 to 14 cents a pound for the green and corrugated species, and from 8 to 10 cents for the black abalone. Most of the dried abalone goes to China and there finally, at retail, brings 75 cents per pound. A camp of 14 Japanese fishermen brings in 30 tons or more of the fresh abalone in a month. There is considerable business in canning abalone for the California markets as well as for New York and Honolulu. The abalone of Japan, the awabi, is a smaller species and the holes of the shell are relatively large, so that only the central part is of value, chiefly for use in inlaying. Gathering abalones is especially carried on by women divers, who swim out to the fishing grounds and work in depths of from 6 to 8 fathoms. Pearls are not often found, but the meat is dried and sold as dark red disks strung on sticks.

The familiar polished abalone shells have gone all over the world and everywhere are highly esteemed as ornaments. The shell is polished by grinding it first on a carborundum wheel until the desired colors are reached. The shell is then surfaced by a wheel of felt sprinkled with carborundum dust glued to the wheel. Finally it is polished with a wheel made of many layers of cotton on the edges of which tripoli has been rubbed. This wheel is revolved about twenty-two hundred times per minute. The quality of being easy, or hard, to grind and polish is spoken of by the manufactures as the texture of the shell.

The shells are sorted into two classes, but ordinarily classes 1 and 2 are mixed together. At Avalon, in 1870, when the meat sold for 5 cents a pound, the green shells brought $80 a ton. At the present time the green shells are sold at $125 to $180 a ton, the black at $80 to $100 a ton, and the red at $40 to $75 a ton. The black shells, with especially good pearly centers, bring from $300 to $500 a ton. Owing to the increasing scarcity of good green shells there is a growing tendency to use the centers of the red shells for jewelry.

When the shells are cut into ornaments, as many as 15 pieces, including one scimitar-shaped paper knife made from the lip, or rim, may be produced from one shell of about 22 inches in circumference. At an average retail price of 50 cents for each of these pieces the products of the shell would realize $7.50.

The blister pearls are more or less extended elevations of the inner, pearly layer of the shell, formed by the secreting cells of the mantle in defense of the invading, boring mollusk, *Pholadidea parva*. They occur mostly in the red abalone, with only one blister pearl in about 1,000 shells of the green or black species. A crab, which infests the abalone at certain seasons, may be the cause of such formations, and one exhibited the complete outline of such a crab. Frequently the blister pearls are formed over sea-urchin spines, chiton, or razor-clam shells, pebbles, and other foreign bodies retained beneath the mantle. Sometimes a diseased visceral hump is cut off and covered by nacre, making a huge blister pearl.

The free pearls have the color of the inside layer of the shell, varying from white to green or pink, according to the species. They sell from 50 cents for the smaller ones to $125 for one of 25 grains. Occasional pearls are so large and of such fine quality as to sell for five hundred or even one thousand dollars. The free pearls are frequently found within the stomach. During the year 1912 over 86,000 blister pearls and 4,000 free pearls were obtained from the abalone fishermen.

The origin of pearls has been a matter for speculation during many centuries. As related in ancient folklore, the pearl oyster, rising to the surface of the sea in the early morning, opens wide the valves of its shell, so that dewdrops may fall within. Under the influence of the air and warm sunshine lustrous pearls develop from these glistening drops of dew. The pearls are white when the weather is fair, but dark if it is cloudy. This belief was held from the first to the fifteenth centuries, when the theory was advanced that the eggs of the pearl oyster serve as nuclei for pearls. About the middle of the sixteenth century Rondelet concluded that pearls form from diseased concretions, and then, in 1600, Anselmus de Boot demonstrated that they are made of the same substance as the shell. Réaumur, in 1717, showed by aid of the microscope that the pearl is composed of concentric layers of nacre, which we now know serve as minute prisms to split up the white light into the rainbow tints so beautiful when reflected from the surface of the pearl. In the middle of the nineteenth century from an investigation of the fresh-water mussels of Turin Lake, Filippe proved that the stimulus for pearl formation in that species is a trematode worm. Other naturalists, Küchenmeister, 1856; Möbius, 1857; Kelaart and Humbert, 1859; Garner, 1871; Dubois, 1901; and Giard, 1903, have contributed to

our knowledge of the origin of pearls from parasitic nuclei. In 1902 Jameson traced the life history of a *Distomum* from its first host, a duck, to a clam, as its second host, and he succeeded in inoculating the edible mussel, *Mytilus*, by placing it with parasitically infected mollusks, and thus artificially induced the formation of pearls. Herdman, in 1903, found in the pearl oysters of Ceylon that a tapeworm larval cyst may become a pearl nucleus, or that in some cases the secretions may be deposited around sand grains, bits of mud, or a fish or some other small animal, in pockets of the mantle epidermis, or again about calco-spherules near the muscle insertions. The surface finally becomes polished, or takes the " orient," and thus reflects the opaline and nacreous tints so highly prized.

The production of culture pearls dates back to the fourteenth century in China, and it is probable that the Arabs had a similar industry. The Chinese open the shell of the river mussel, push back the mantle, and introduce metal images of Buddha, which are covered with nacre in the course of six months. Linné drilled a hole through the shell and inserted a pellet of limestone on the end of a silver wire, so that the nucleus might be kept free from the shell during the secretion of nacre. In more recent times the secretion of culture pearls has been induced in pearl oysters by similar methods in various countries. Bouton, in 1897, at Roscoff, France, bored small holes through the shell of the abalone, and inserted forms made of mother-of-pearl. After some months beautiful pearls were secreted, their size being in proportion to the length of time of the culture.

In our red abalone a boring mollusk, *Pholadidea*, penetrates the shell from the outside. It files its way by means of sharp teeth on its shell, and possibly by the secretion of sulphuric acid. The burrow enlarges as the *Pholadidea*, growing in size, digs its way in. When near the inner pearly layer of the abalone shell the host resists the oncoming *Pholadidea* by secreting more nacreous matter. Thus the defensive wall, eaten by the *Pholadidea*, grows inwardly as a mound-shaped projection, the blister pearl. In imitation of this natural process a hole is drilled through the abalone shell and a form is inserted. This form, made of shell, is shaped like a long-shanked collar button, and so placed that the expanded curved base lies against the pearl-secreting mantle. The shank projects from the outer surface of the abalone shell and is there made fast by aluminum wire, to which a metal tag bearing the serial number is attached. In some cases the wire has corroded, with the loss of the tag. In later experiments the numbers have been filed upon the shell. The black abalone has been used in most cases, although a few experiments have been made upon the green abalone. Holes have been drilled through various parts of the shell and different numbers of forms inserted. In addition, spherical forms, without shanks, have

been placed beyond the mantle cavity near the visceral hump. I have succeeded in raising abalone culture pearls in 133 days. These pearls, however, are thin layers of nacre, formed over a horny basis, which is the first material to be secreted. In the natural process of continued deposition they increase in thickness and solidity, and consequently in value. One produced in a green abalone in seven months shows good form and luster. My average time for drilling a hole in the abalone shell, inserting the form, and wiring it in place with the numbered metal tag is eight minutes. This working time might be decreased by an expert laborer doing nothing else, so that the business of raising pearls would be of interest and profit. Mr. C. B. Linton has succeeded in producing similar culture pearls by drilling a hole through the shell center, pushing in a round ball made from shell, and filling the outside end of the hole with beeswax and cement.

Based upon the fact that each ton of abalone shells represents a certain value of manufactured jewelry and novelties, it is possible to estimate the value of the abalone industry. Shells of the black abalone are sorted into two classes. Each ton of those with fine, pearly centers will make novelties and jewelry worth, at retail, $4,000. The class known as button shells, with plain mother-of-pearl surface, represents a final value of $1,000, and the shells of the green abalone $3,000. For the fiscal year ending in July, 1912, the following shipments were made from Long Beach and represent the given valuations in manufactured products: Thirteen tons of pearl-center black abalone shells, $53,000; 40 tons of button black abalone shells, $40,000; 14 tons of dried abalone meats, at $200 a ton, $2,800; a total of $95,800. The shipping statistics are not complete for the other California ports, but it is demonstrable that the abalone industry may be developed into one of great value.

Much has been said recently in the newspapers concerning the threatened extermination of the abalone. That this is a real danger and not an idle theory is apparent to anyone familiar with the facts. For instance, near Avalon, Santa Catalina Island, not more than 20 years ago the green and corrugated abalones were so thick that they rested upon one another four or five deep all over the rocks. After much searching in this locality during the last year I was unable to find a single specimen. The shells brought up by the divers of the glass-bottomed boats, and eagerly bought by the tourists, have been placed in position previously by the enterprising management. Great shell heaps on San Clemente, San Nicholas, and other islands prove the abundance of abalones during the centuries of Indian occupation. Some of the red shells found are unusually large, measuring from 20 to 30 inches in circumference. Necklaces of large abalone pearls have been found with the remains of Indians. If only well preserved, some of these pearls at present would be worth as much as $500.

In many places where the abalone was formerly abundant, the large individuals of legal size are taken and it may be true, as in the case of the American lobster, that in this manner the most prolific breeders are sacrificed. We do not yet know anything about the breeding habits and embryology of any species of the abalone, and hence are not certain as to the best months for a closed season. In time, without doubt, we shall be able to artificially propagate the abalone, as has been done with the oysters, clams, lobsters, and other useful animals. The Government breakwater at the mouth of Los Angeles Harbor, at San Pedro, has become a natural breeding ground for black abalones, which creep back under the great stone blocks and thus escape the gatherers, who are stripping every accessible niche and cranny along the coast at each low tide during the open season.

Reservations have been established at Monterey Bay and Venice, but the present laws are inadequate for their best development. By act of the city trustees the Venice Breakwater has been made a biological reservation, under the control of the marine biological station of the University of Southern California and guarded by a deputy of the State fish and game commission. As an aquicultural experiment I have placed colonies of several hundred black abalones and 75 of the green species upon the submerged rocks. A large concrete live box has been suspended by a block-and-tackle hoisting apparatus at about mid height of the tide. The open top is covered by heavy galvanized-iron meshwork, while through several holes in the bottom the dirt is cleaned out by the flow of the tide. The box is so heavy that one may stand upon any part of it and do the necessary work in feeding and observing the animals within. Forty abalones under experimentation and for growth records are kept in the live box, and a group of two or three times that number might easily be maintained in good condition. Near Venice the ocean is shallow, for it is 3 miles out to the 16-fathom line. The trawling of our motor sloop, the *Anton Dohrn*, has demonstrated that in most places the fauna of the sandy bottom is poor. Better results may be looked for when reservations are located on the rocky coast, where great beds of kelp thrive just within the deep-water line. The kelp is not only important as food for abalones, but within its wide-spreading fronds a world of living things thrive. In such a region the plankton is richer and these microscopic plants and animals generate food for the larger swimming and bottom-dwelling forms.

The establishment of laws for the regulation of aquiculture and the concomitant protection of marine and fresh-water organisms is of primary importance. The formation of reservation districts for absolute closure during successive periods of years, within which we may have, every 5 or 10 miles, smaller perpetual biological reservations for breeding centers, will solve the problems of preservation in a better manner than the present laws for closed and open seasons. In

Germany the Elster River pearl-mussel beds and in France the marine mussel and oyster fisheries have been saved and developed by proper legislation and governmental supervision. In this country the business of oyster propagation and farming has been profitably established under such well-delevoped laws as those of Connecticut. It would be difficult to attempt an estimate of the remarkable achievement of the Bureau of Fisheries in the field of aquiculture. The shad, the salmon, and now the fur seal have been saved from extermination. So abalones may be raised in the sea as easily as chickens upon the land. The coastal waters must be surveyed for leasing by the State and then a police force organized to guard the marine farms from all the poaching pirates. It can not be emphasized too often that in direct ratio with the increase of population the neglected food resources of land and sea must be conserved and developed. The company manufacturing rubber and fertilizer and extracting iodine from kelp should only be allowed to cut the seaweed under such restrictions as will preserve the natural home and food supply of all the countless dependent organisms. The inherent tendency of man to rob the earth and sea in order to promote his own selfish interests must be restrained for the larger benefit of his fellows and the salvation of his descendants from want. The sea is the last great field for human exploration and exploitation. We know so little of its vast resources that we can scarcely dream of the possible future industries which will arise under a wisely administered system of aquiculture.

PLATE 1.

THE DIVER GOING DOWN THE LADDER.

IN DIVING DRESS READY FOR THE DESCENT.

THE GREEN ABALONE SHELL WITH MASK OF ALGÆ.

BLACK ABALONE.

Shell removed, showing visceral
mass terminating in the spiral
coecum posteriorly and the opened
gill cavity to the left anteriorly.
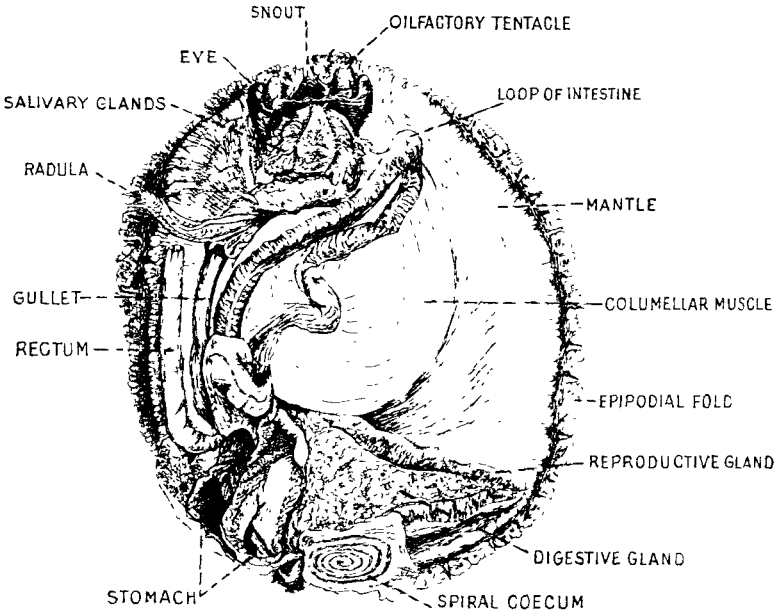
GREEN ABALONE DISSECTED.

The gills, kidneys, heart, and dorsal parts of mantle and columellar muscle have been
removed and spiral coecum turned over to the right

FEEDING ABALONES FROM THE HAND

a, b, grasping kelp with anterior processes of foot, *c,* drawing kelp under foot *d,* eating hole in kelp.
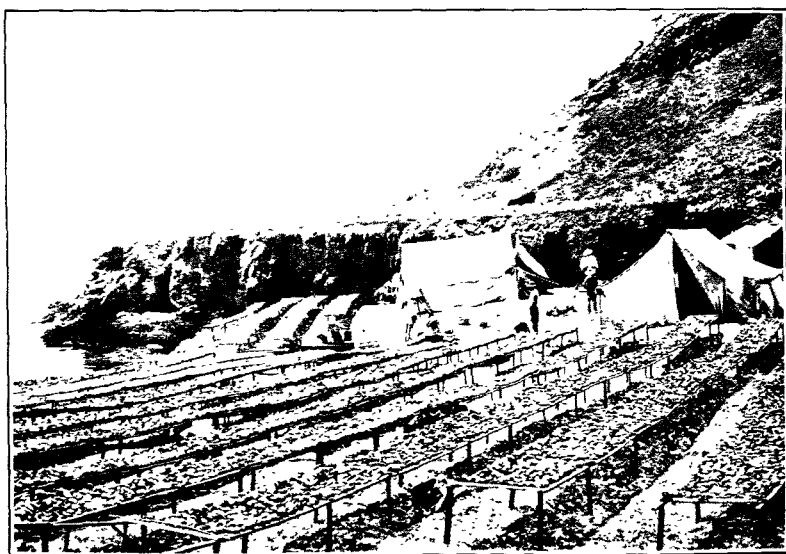
THE ABALONE DRYING FRAMES OF THE SAN CLEMENTE ISLAND JAPANESE CAMP.

DIPPING ABALONES FROM THE BOILING TANK.

MEAT OF THE GREEN ABALONE DRYING IN THE SUNSHINE AT SAN CLEMENTE ISLAND.
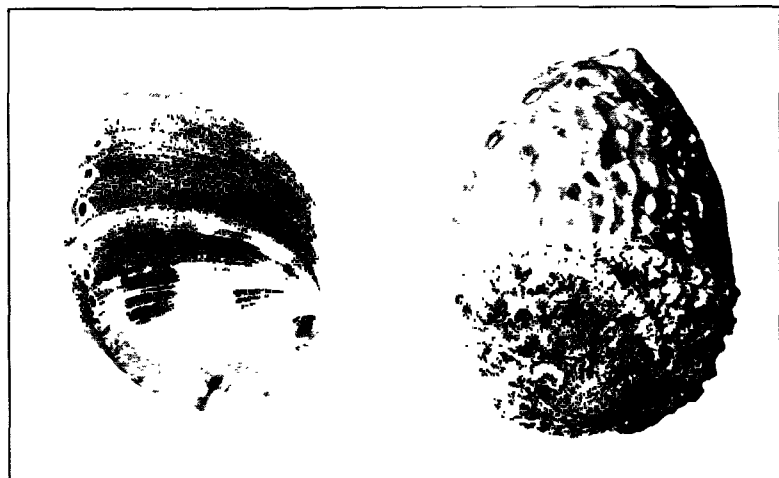
POLISHED BLACK ABALONE SHELL   SHELL OF THE CORRUGATED ABALONE.

The unpolished posterior half showing in-
crusting worm tubes.

A PORTION OF THE RED ABALONE SHELL WITH FOUR BLISTER-
PEARLS AND TWO FREE PEARLS.

SHELL OF RED ABALONE OPENED TO SHOW A RAZOR-CLAM
SHELL FORMING A BLISTER-PEARL NUCLEUS.
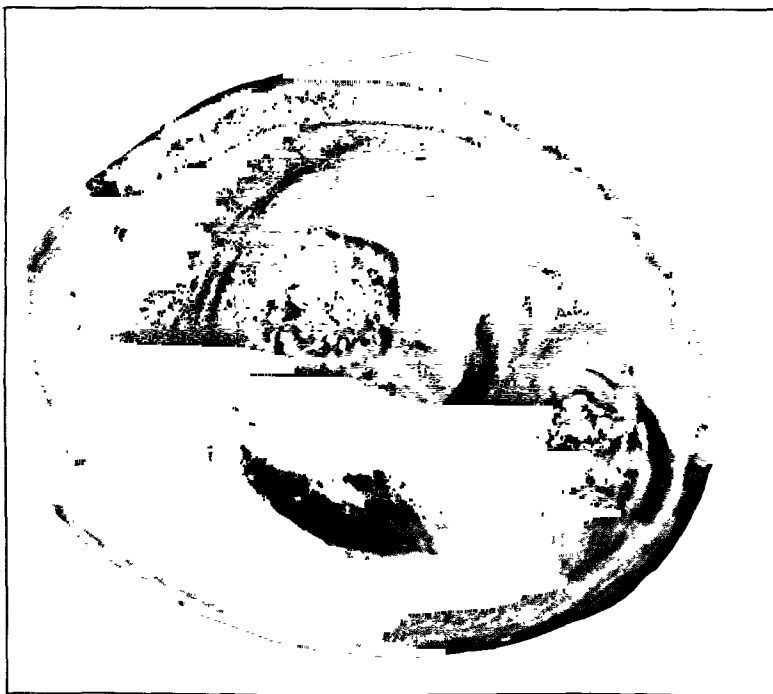
BLISTER-PEARL FORMED OVER A DISEASED VISCERAL HUMP.

PLATE 7.
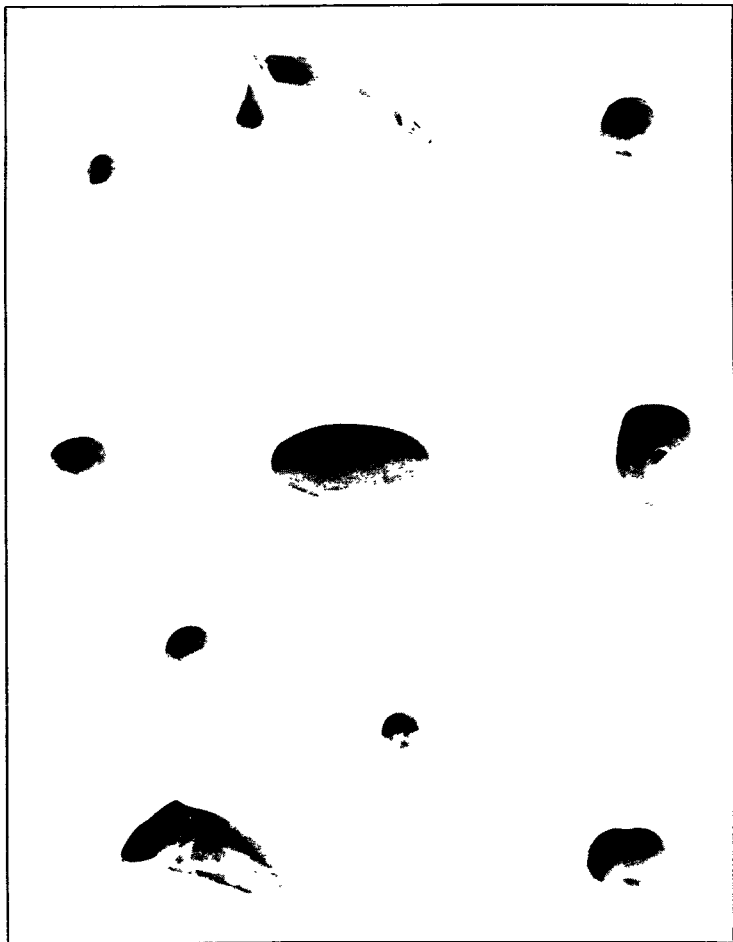
FREE PEARLS FROM THE ABALONE.

The central pearl large and valuable. From the collection of C. B. Linton.
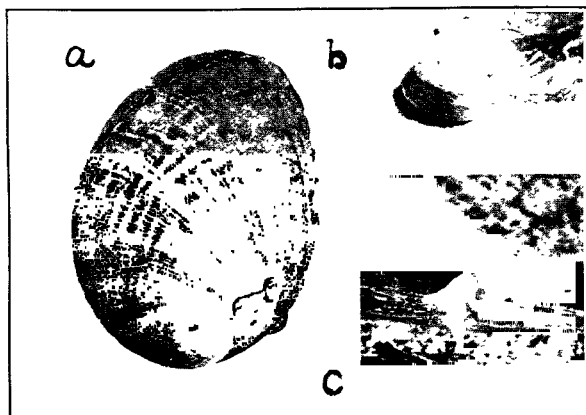
a, black abalone shell with pearl form inserted. b, head of shell pearl form on inner side of black abalone shell. c, culture pearl formed in the green abalone in seven months.
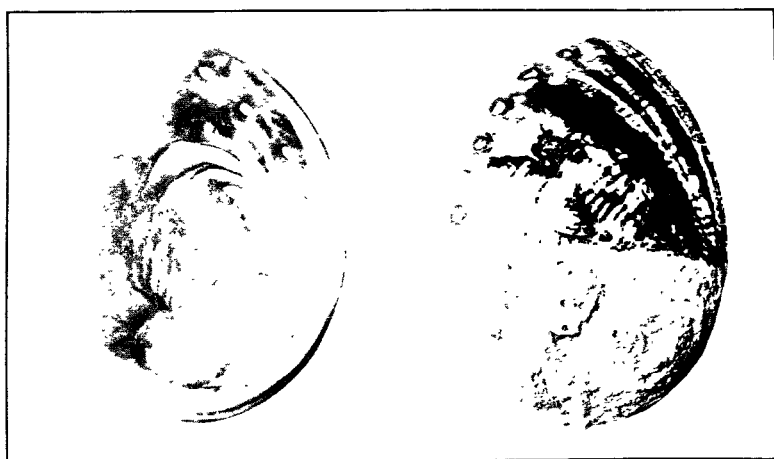
INTERIOR VIEW OF THE RED ABALONE SHELL.

Showing pearly center within the muscle scar.

SHELL OF THE GREEN ABALONE.

The anterior portion polished
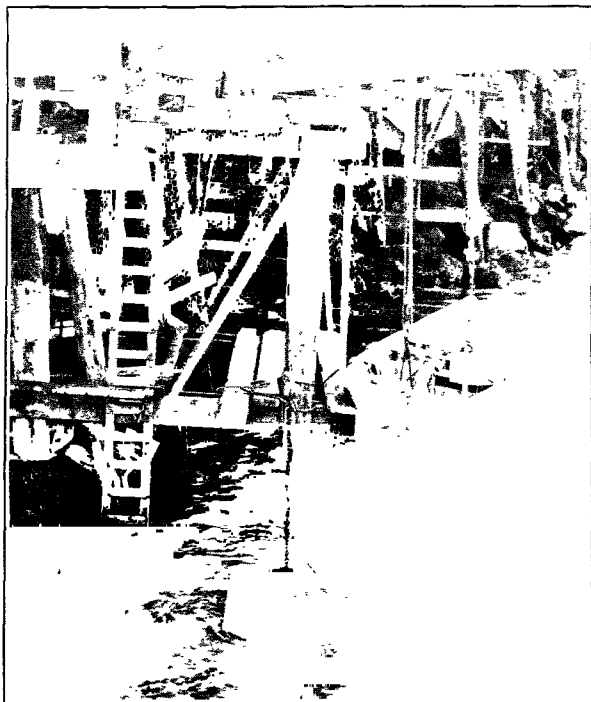
THE CONCRETE LIVE-BOX ABOVE WATER AT LOW TIDE.

THE JAPANESE ABALONE CAMP AT WHITE'S POINT, CALIFORNIA.

PLATE 10.
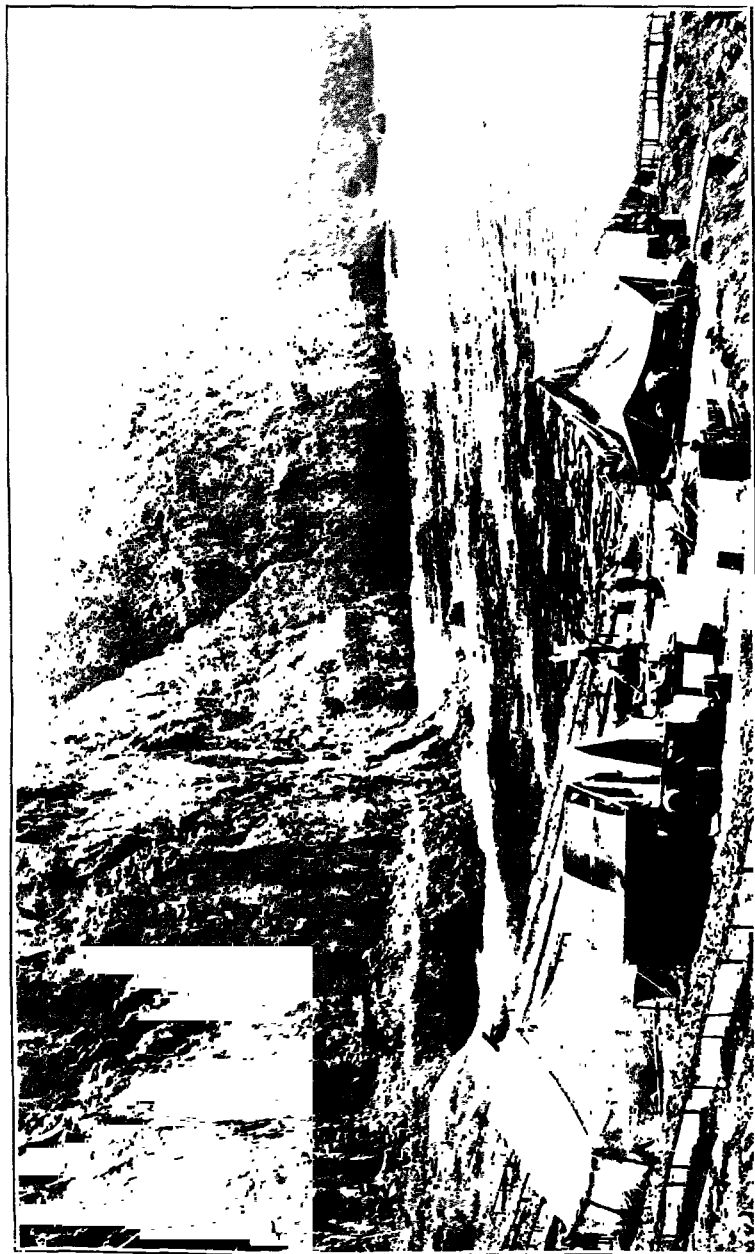
THE JAPANESE CAMP AT SAN CLEMENTE ISLAND.

THE VALUE OF BIRDS TO MAN.

By JAMES BUCKLAND,
London, England.

I saw with open eyes	*I saw in vision*
Singing birds sweet	*The worm in the wheat,*
Sold in the shops	*And in the shops nothing*
For people to eat.	*For people to eat;*
Sold in the shops of	*Nothing for sale in*
Stupidity Street.	*Stupidity Street.*

—Ralf Hodgson.

NUMBER, FECUNDITY. AND VORACITY OF INSECTS.

Man imagines himself to be the dominant power on the earth. He is nothing of the sort. The true lords of the universe are the insects. While it is true that man has invented and perfected so many destructive agencies that he has attained to a predominance over the most fierce and powerful mammals and the most deadly reptiles, it is also true that in face of an attack of insects he and all his works are set at naught.

"A little one shall become a thousand and a small one a strong nation." Few people know how enormous is the number of insect species or how amazing is their power of multiplication. The number of insect species is greater by far than that of the species of all other living creatures combined. Over 300,000 have been described, and it is considered not improbable that twice that number remain to be described. Practically all living animals, as well as most plants, furnish food for these incomputable hordes. More than this, Kirby, in the "Introduction to Entomology," devotes no less than five entire epistles to the injuries we sustain from insects, while two only are sufficient to describe the benefits they yield.

The fecundity of certain insect forms is astounding, the numbers bred reaching such prodigious proportions as to be almost beyond belief. Riley once computed that the hop aphis, developing 13 generations in a single year, would, if unchecked to the end of the twelfth generation, have multiplied to the inconceivable number of ten sextillions of individuals. Noting the preceding, Forbush says if this brood were marshaled in line, 10 to the inch, it would extend to a point so sunk in the profundity of space that light from the head of the procession traveling at the rate of 184,000 miles per second would require 2,500 years in which to reach the earth.

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Kirkland has computed that one pair of gypsy moths, if unchecked, would produce enough progeny in eight years to destroy all the foliage in the United States.

A Canadian entomologist states that a single pair of Colorado beetles, or potato bugs, as we call them, would, without check, increase in one season to 60,000,000. At this rate of multiplication the disappearance of the potato plant would not be long delayed. The chinch bug, a fecund and destructive pest, has been found in a clump of grass 8 inches in diameter to the number of 20,000. The progeny of this colony alone, if unchecked, would soon become incomputable hordes, devastating wide areas of the earth's surface. Those of you who have been in South Africa probably have seen locusts in flight which filled the air and hid the sun. What a potency for evil lies hidden in the tiny but innumerable eggs of these ravening pests! If every egg was permitted to hatch and every young locust to come to maturity, the consequences would be too dreadful to contemplate.

The voracity of insects is almost as astounding as their power of reproduction. The daily ration in leaves of a caterpillar is equal to twice its own weight. If a horse were to feed at the same rate, he would have to eat a ton of hay every 24 hours. Forbush says that a certain flesh-feeding larva will consume in 24 hours 200 times its original weight, a parallel to which, in the human race, would be an infant consuming, in the first day of its existence, 1,500 pounds of beef. Trouvelot, who made a special study of the subject, affirms that the food taken by a single silkworm in 56 days equals in weight 86,000 times its original weight at hatching. What a destruction this single species of insect could make if only a one-hundredth part of the eggs laid came to maturity!

MISSION OF THE BIRDS IN ORGANIC NATURE.

Who or what is it that prevents these ravening hordes from overrunning the earth and consuming the food supply of all? It is not man. Man, by the use of mechanically applied poisons, which are expensive, unnatural, and dangerous, is able to repel to an extent the attacks on his orchard and garden. Out in the fields and in the forests he becomes, before any very great irruption of insects, a panic-stricken fugitive. Neither is it disease, or the weather, or animals, or fungi, or parasitic and predaceous insects within their own ranks. However large may be the share of these particular natural agencies in keeping insects in check, experience has shown that it is lamentably insufficient. Then what is it? The bird. Bird life, by reason of its predominating insect diet, is the most indispensable balancing force in nature.

MAN AT WAR WITH NATURE'S LAWS.

Yet man has been engaged in the past half century in the blind and wanton destruction of this essential part of nature's great plan. He has taken no thought of the needs of the hour, nor concerned himself with the wants and claims of those to come. Within the space of a few years, under no constraint of necessity, he has carried out a policy of destruction more effective than that accomplished in centuries by the slow processes of nature. Armed with a weapon that annihilates space, he has constituted himself the master and the ruler of the animal world, and has delegated to himself the right to adopt a utilitarian standard by which he measures the value of all other forms of life. It is not for man to say what shall live and what shall be destroyed. The whole system of nature is in exquisite poise, and it is not possible to lay rough hands upon it without disturbing it in directions and on a scale which at the time may not be guessed at. If we remove or reduce the working power of one living organism which acts as a check on another, the latter, freed from restraint, will inevitably multiply. As we destroy the insect-eating birds the insects on which they prey will multiply to scourge us as Egyptian plagues. It is a fact which agriculture has learned to its cost in many parts of the world.

SERIOUS CONSEQUENCES OF BIRD DESTRUCTION.

Some years ago the agriculturists of Hungary, moved to the insane step by ignorance and prejudice, succeeded in getting the sparrow (*Passer domesticus*) doomed to destruction. Within five years the country was overrun with insects, and these same men were crying frantically for the bird to be given back to them, lest they should perish. The sparrow was brought back, and, driving out the hordes of devastating insects, proved the salvation of the country.

In the island of Bourbon once, because of the same ignorance and prejudice, a price was set on each martin's head. The birds all but disappeared, and grasshoppers took possession of the island. The edict of banishment was hurriedly revoked and the exile recalled. Fortunate, indeed, was it for the island of Bourbon that the bird was not beyond recall.

During the year 1861 the harvests of France gave an unusually poor return, and a commission was appointed at the instance of the minister of agriculture to investigate the cause of the deficiency. By this commission the deficiency was attributed to the ravages of insects which it was the function of certain birds to check. These birds, it appeared, had been shot, snared, and trapped throughout the country in such numbers that but little repressive influence had been exerted upon the insects. It was concluded that by no other

agency than the birds could the ravages of insects be kept down, and the commission called for prompt and energetic remedies to prevent the destruction of birds.

For some years prior to 1877 vast numbers of red-winged black-birds were poisoned in the spring and autumn around the cornfields of Nebraska. This was done in the belief that the blackbirds were damaging the crops, especially the wheat. Great numbers of prairie chicken, quail, plover, and various other insect-eating species were destroyed at the same time by eating the poisoned grain. Then came 1877, and with it Nemesis. The locusts appeared in countless numbers. There were no birds to eat them, and Nebraska mourned.

In 1895 the ravages of two species of cut-worms and some 10 species of locusts produced a famine in the region of Ekaterinburg, which is in Russian Siberia. The local Society of Natural Sciences inquired into the cause which had permitted such a numerous propagation of insect pests, and reported that it was due to the almost complete destruction of birds, most of which had been killed and sent abroad by wagon loads for millinery purposes.

Those grass ticks which now make the keeping of most breeds of cattle impossible in Jamaica, are not mentioned in the records of the early nineteenth century. The appalling destruction in more recent years of insect-eating birds, chiefly to supply the demands of the millinery market, has led to an inordinate increase of the ticks and to the dying out of all but Indian cattle. This correlation of birds and ticks—to say nothing of mosquitos and other insect plagues in Jamaica—was put fully and circumstantially before the secretary of state for the colonies by a deputation in 1909.

E. D. Morel has recently pointed out how the reckless destruction of the guinea-fowl (*Numida*) in French West Africa is coincident with the increase of certain germ diseases, and, above all, with ravages to crops on the parts of the larger insects, especially beetles, the grubs of which were devoured by the guinea-fowl, which scratched them out of the ground.

Though I could give a hundred cases similar to the foregoing, I must rely on the few I have cited to show that the wholesale destruction of birds is surely followed by disaster to man.

VALUE OF THE BIRD IN CHECKING INSECT IRRUPTIONS.

When the Mormons first settled in Utah, their crops were destroyed utterly by myriads of black crickets that streamed down from the mountains. Promising fields of wheat in the morning were by evening as bare as though the land had not been sown. The first year's crop having been destroyed, the Mormons had sowed seed the second year, and again the crop promised well. But again the

crickets appeared, devouring every blade of wheat, and the follow-
ers of Joseph Smith were on the verge of starvation. At this junc-
ture Franklin's gull came by hundreds of thousands, and, feeding
greedily on the crickets, freed the fields of the pest. The settlers
at Salt Lake regarded the advent of the gulls as a heaven-sent
miracle, and practically canonized the birds.

Since that hour this black-headed gull has remained a faithful
servitor of the farmers of Utah. At the present moment a move-
ment is on foot to erect a monument to this bird in Salt Lake City,
thus showing a befitting and seemly sense of gratitude for its in-
estimable services in guarding the State from the ravages of insects.

It is a common practice with all settlers in a new country to at
once set about killing the native birds in a thoughtless and foolhardy
manner. This stupid practice is all the more deplorable, because
an enormous increase of insect pests invariably attends the operations
of the pioneer agriculturist. Finding in cultivated crops new and
more succulent sources of food supply, insects change their primitive
habits, to swarm and multiply exceedingly upon the fertile fields of
man's creation.

When the farmers in New Zealand began to break the virgin soil
on an extensive scale, a certain caterpillar, which hitherto had
gleaned a somewhat meager sustenance from the scanty native
verdure of the open lands, disappeared from its old haunts and at-
tacked the cultivated areas. So speedily did it increase by reason
of a more favorable environment that it soon became a blasting
plague. It came not singly, nor even in battalions, but in mighty
armies which laid waste the land. I have seen these atoms cover the
pastures in such numbers as to make the green one brown. I have
seen countless millions of them pass out of one cornfield, having
stripped every stalk bare, cross the road in solid phalanx, and pass
into another. I have seen big mobs of sheep mustered in hot haste
and driven to and fro over these serried ranks that they might crush
them with their scurrying feet. I have seen every horse roller in
a district brought up hurriedly, like steam engines to a fire, and
drawn backward and forward over the crawling masses until the
cylinders stuck fast in a mire of squashed insects. I have seen
huge ditches dug in an attempt to stop the invaders' progress. The
effort was as futile as that of a child who builds a bank of sand by the
sea, thinking it will stem the oncoming tide. Even railway trains
were brought to a standstill, the wheels of the engines being unable
to grip the rails owing to the hordes of caterpillars which were
crossing the line.

In time it became abundantly clear that if this disastrous condition
of affairs continued it would be useless to attempt to carry on agri-
culture in New Zealand. Realizing that any attempt which they

might make to rid the smitten land of the plague would be but a mockery, the farmers turned their eyes longingly to the natural enemy of the caterpillar—the bird. But the native birds—though they had lived in closest companionship with the Maoris—had been taught the treachery of the white man in a school that reeked with blood, and those that had not been killed had retreated from the vicinity of the settlements, visiting the insect-ridden fields occasionally only.

Wherefore insectivorous birds from the old country were introduced, and the one that multiplied most rapidly was the common house sparrow. And *Passer domesticus* soon cut short the career of the caterpillars.

As digestion is exceedingly rapid in birds, and as they feed for the most part throughout the day, they are peculiarly adapted for the suppression of abnormal outbreaks of vegetable as well as of animal life.

That formidable imported weed, the Scotch thistle, threatened at one time to overrun the whole of New Zealand. Much time and money was spent by the settlers in cutting off the plants close to the ground, and in pouring turpentine upon the split stumps, hoping thereby to kill the roots. Vain labor. The wind-driven clouds of thistledown, which were planting the weed far and wide, grew yearly denser and more frequent. At length the fields became a packed growth of prickly plants, which nothing could face.

The sparrows took to eating the seed. In tens of thousands they fed on it, giving it the preference of all other hard food, and the weed was conquered.

To-day in New Zealand the sparrow is looked upon as an impudent thief without a redeeming feature in its character. No one, of course, can say what would happen if the bird was dismissed from the country, though it is probable that the Dominion would be again overrun with caterpillars and thistles. Setting aside this hypothetical question, the good the sparrow does must far outweigh the evil. This statement receives confirmation in the bountiful harvests with which New Zealand is blessed. Never were the sparrows more numerous; never the complaints against them more bitter; yet the yield of grain is without precedent.

The growling of the New Zealand farmer at the sparrow justifies Virgil's complaint of the "miserly husbandman." Miserly, indeed, and blind. Not a grain will he give to the bird which has labored unceasingly with him for the production of his crops; but whole fields of wheat to the caterpillar.

Parenthetically I may mention that, though I have written here in defense of the introduction of the European sparrow into New Zealand, I am not an advocate of acclimatization. It is true that one can point to cases where a foreign bird has been introduced to per-

form the function of a native species that has been driven out, and where that function has been performed satisfactorily. But, as a rule, such substitutions are fraught with danger. Birds so rapidly change their habits in new surroundings that few species remain loyal to the reputation for honesty which they enjoyed in the land of their origin. Like most aliens, it would have been better had they remained in their own country. Although the spread of civilization unconsciously demands some victims, man and indigenous birds can, speaking generally, occupy the same territory without much difficulty. If one requires proof of this, he has but to turn his thoughts to British India, where native birds of all kinds, owing to the protection accorded them by the Hindu doctrine of the sanctity of all life, are found living in closest proximity to dense human populations.

The moral of all of which is that it behooves every man who has the welfare of his country at heart to do all in his power to foster native birds.

In Australia a plague of grasshoppers periodically visits the fields to devour the crops. The ruin they would otherwise bring on the farmer is averted by the good offices of ibises and other native birds. As a destroyer of grasshoppers, the straw-necked ibis (*Carphibis spinicollis*) has no equal among birds. Dudley Le Souëf, the director of the Melbourne Zoological Gardens, some years ago visited a rookery of this bird in the Riverina, and, after a careful estimate, came to the conclusion that the minimum number of birds breeding there was 200,000. He procured a number of specimens and ascertained by actual counting that the contents of an average crop of an adult bird were 2,410 young grasshoppers, 5 fresh-water snails, and several caterpillars, which, multiplied by 200,000, amounts to a total of four hundred and eighty-two million and odd grasshoppers, as well as vast numbers of caterpillars and snails. " Then, again," says Mr. Le Souëf, " the average number of young is about two and one-half to each pair of parent birds, and the contents of their stomachs must reach an enormous total, as they all seemed gorged with food."

As this enormous amount of food is being eaten every day by ibises in Australia during the hatching time of the grasshoppers, some little idea can be formed of the immense utility these birds are to the farmer. Without them the balance of nature would be disturbed and successful agriculture would be impossible.

In addition to its great value as a destroyer of all-devouring insects, the straw-necked ibis feeds with avidity on the fresh-water snail—the host of the dreaded liver fluke, which sheep so easily get in certain damp localities.

Yet, in face of these facts, people surreptitiously visit the breeding grounds of these birds and collect their eggs by the cartload. One party in 1912, having gathered more than it required, drove away and left 4,800 eggs to rot on the ground.

THE VALUE OF BIRDS IN FORESTS.

Omitting all mention of many another notable instance of the quelling of insect outbreaks by birds, I will pass at once to the consideration of those perennial services which act as a constant check on the undue increase of insects, rodents, weeds, and other pests.

Birds attain their greatest usefulness in the forests, because the conditions there closely approach the primeval.

Forest trees have their natural insects foes, to which they give food and shelter, and these insects in turn have their natural enemies among the birds, to which the tree also gives food and shelter. Hence it follows that the existence of each one of these forms of life is dependent upon the existence of the others. But for the trees the insects would perish, and but for the insects the birds would perish, and but for the birds the trees would perish; and, to follow the inexorable laws of nature to the conclusion of their awful vengeance, but for the trees the world would perish.

Consider for a moment the life of a tree in connection with the insects that prey upon it. At the very beginning, before the seed or nut has germinated, it may be entered by a grub which destroys it. Should, however, the seed or nut be permitted to grow, the roots of the seedling may be attacked by bettles. Escaping this danger, a worm lays its eggs in the cracks of the bark. On hatching, the worm or borer perforates a hole in the stem. This hole, admitting water from every passing shower, causes a decay in the wood to commence, from which the tree may never recover. Other borers feed upon the bark, eating the soft inner layer and the sap. The twigs are affected by the larvæ of certain bettles, which act as girdlers, sometimes destroying limbs over an inch in diameter. Weevils bore under the bark and into the pith, making excavations in which the eggs are laid. For the same purpose the cicada makes a terrible wound, which often proves fatal. The limbs of trees are affected by aphides, which puncture them and feed upon their juices, exhausting the sap. Many species of plant lice and scale insects infest trees, doing great damage, while over 100 different species of gall flies are parasitic upon them. The buds of trees are entered and destroyed by the larvæ of certain moths, while the leaves are devoured by caterpillars. To take the oak as an example, it is known that altogether over 500 species of insects prey upon it. Finally, be it remembered that in the bark and in the underlying tissues lie the vital energies of a tree.

It is difficult to perceive the usefulness of these insects which feed on the different parts of the tree, though they may, perhaps, when in normal numbers, exert a useful influence by a healthful and necessary pruning. It is certain, however, that if they were not in turn

preyed upon by birds they would so increase in numbers that the tree could not survive the injuries they would inflict.

How dependent trees are on birds for their existence may be gathered from the following illustration: As many of you probably know, trees breathe through their leaves. Consequently, if the buds' of the leaves are prevented from developing, or are eaten, when developed, by caterpillars, the tree is weakened. Many coniferous trees will die if stripped of their foliage for one year. Deciduous trees, if deprived of their respiratory organs for several years in succession, will also perish, though these trees linger as a rule for two or even three years before finally succumbing.

Now, injury to its breathing organs is not the only danger to which a tree afflicted in this way is subjected. The tree, being in a weakened condition, is at once beset by beetles and other borers, who, multiplying rapidly under such favorable conditions, tunnel under the bark until all the vital tissues of the poor tree are wasted. Thus a tree which might have recovered from the injury to its lungs falls a victim to the attacks of an insidious enemy which took advantage of its enfeebled state.

Woodpeckers or other birds of similar feeding habits would have flown to the rescue of the tree and possibly saved its life; but when that corrective influence is missing, the tree must die.

This illustration of the dependence of the tree on the bird and of the bird on the tree is, of course, but one of a long series that could be cited, and it is because of this most delicate adjustment between the tree, the insect, and the bird that I regard as profoundly true Frank M. Chapman's statement "that it can be clearly demonstrated that if we should lose our birds we should also lose our forests."

It is an ignorant schoolboy who does not know that if we lost our forests we should lose also the moisture necessary for the production of crops upon which man is dependent for his living.

If, in his arrogance and folly, man exterminated the bird, thinking himself capable of taking its place, he might be able to make shift with his sprays to save some portion at least of his orchards and gardens; but of what avail would be his puny efforts to protect from the ravening maws of insects the forests of America and Africa, the jungles of Asia, or the bush of Australia? Should he not, then, protect by every means in his power every one of the forest birds, who, as a matter of course, and without trouble or expense to him, ordinarily accomplish, on his behalf, the herculean task of saving the lives of the trees? One would think so. Yet in these very regions, in these vast areas of valuable timber, every trunk of which man will some day need, there are being killed annually millions of the feathered guardians of the tree, and killed, too, for no worthier purpose than that, dead, they may defame a woman's head.

THE VALUE OF THE BIRD IN THE ORCHARD.

For man's purposes the work of the bird in the orchard is not so thorough as that done by them in the forest. Birds are the slaves of ·nature, and, in the main, nature's endeavors are put forth only to produce such fruits as will insure the perpetuity of each species of tree. With man the case is altogether different. His main object is not the propagation of trees, but the production of a giant gooseberry. Moreover, by introducing arsenical spraying, tarred and greased bands, and other devices to counteract the evil action of insects, he has, to a certain extent, taken upon himself the office of the bird. In this he is wise, for it must be admitted that if he wishes a large crop of fruit he must himself prevent the inroads of those insects which attack the fruit directly. It can not be expected of the bird that it will become an efficient ally of man in protecting the artifically produced fruit from the attacks of the numerous insects that are drawn to the orchard by a vastly increased quantity of fruit of a vastly better quality than the natural product.

For all that, fruit growers are largely indebted to the bird for a great part of their annual crop.

In the Union of South Africa, for instance, it is found that near towns, where the birds have been more especially persecuted and driven away, the growing of fruit and other market produce has become increasingly difficult, or even impossible, owing to the preva lence of insect pests which are not affected by spraying operations.

But let us suppose for a moment—though the supposition is absurd—that the modern fruit grower could do without the services of the bird. Would that give him a right to slay it? Apart altogether from the agriculturist, what of the millions of people who, as an increment to their ordinary livelihood, grow fruit, but who can not afford either the time or the money to treat their trees in the most approved and scientific way?

What would happen to this poorer class of fruit growers if they were deprived of the services of the bird is best seen in what happened to Frederick the Great. This worthy, in a fit of passion because a flock of sparrows had pecked at some of his cherries, ordered every small bird that could be searched out to be instantly killed. Within two years his cherry trees, though bare of fruit, were weighed down with a splendid crop of caterpillars.

Call the bird in the orchard an evil, if you will; but it is a necessary evil, and the fruit grower must make up his mind to pay the bird its wages lest worse befall.

THE SERVICES OF THE BIRD IN THE GARDEN.

The garden is the insect's paradise. It fares sumptuously every day on the most succulent of vegetable foods. Every opportunity is thus offered for its increase. The greatest insect enemy of the gardener is a small, dull-colored, hairless caterpillar known as the cutworm, which is the larva of a Noctuid moth. This chief of the brigand band of garden pests usually hides during the day beneath matted grass or under the loose soil along the rows of plants. It comes forth at dusk to feed. The bird is abroad at the first peep of day, and it finds the robber worm in the morning before it has retreated to its place of concealment.

But the early bird has to come stealthily to the garden to catch the worm. Its visits are regarded by man with more than suspicion, and it is fortunate if it escapes with its life. In consequence it snaps up a caterpillar and is off again, leaving thousands it would have eaten, if unmolested, to run riot amongst the vegetables.

Occasionally a bird more bold than its fellows will visit the garden in broad daylight to dig the cutworms out of their hiding places. Nature never having begrudged it the reward of its toil, the bird takes a few peas before leaving.

The gardener notices the damage done to his peas, and next morning is up betimes. He sees the bird running along a row of peas, stopping frequently to peck at something on the ground. There is a loud explosion, followed by a puff of smoke. The smoke slowly drifts away, to disclose a bird lying dead.

Caterpillars are not gifted with voice; if they were, they would scarce forbear to cheer.

The bird is dead. Mark the sequel. One fine morning the gardener issues proudly forth to cut his mammoth cabbage—the one with which he intends to put to utter confusion all other competitors at the local fruit and flower show. Alas for human hopes and the depredations of caterpillars. The cabbage is riddled like a colander.

The gardener when he shot the bird forgot, if, indeed, he ever knew, that the ancient law forbade a muzzle to the ox that thrashed out the corn.

UTILITY OF BIRDS IN THE MEADOW.

Each season, until hay making commences, the grass offers cover and shelter for the nests of such birds as breed on the ground. The fields also provide food for birds, and for the insects on which birds feed. Thus there is established a natural interrelation and interdependence between the bird and its food and shelter—that is to say, the insects and the grass. This simulates the condition of the earth before man made discord in the grand harmony of nature's laws.

Where the birds of the field are undisturbed they tend to hold the grass insects in check. On the other hand, when the numbers of birds in the field are for any reason insufficient, the insects increase.

Here is an instance of this: Some years ago in Bridgewater, Mass., a great battue was held by the ignorant townspeople in the spring of the year, and so many field birds were killed that their dead bodies were plowed into the land for manure. The following summer whole fields of grass withered away and died. This was due solely to the fact that the number of field birds had been reduced, and in consequence the pressure which nature demands the field birds shall exert upon the field insect had been released.

Again, at one time in New Zealand it was no uncommon thing to see English grass wither up in large patches, as though scorched by fire. This was due to the work of a crane fly and click beetle, the larvæ of both of which were addicted to the habit of eating the roots of the grass, just under the surface. English grass was then comparatively limited in the up-country districts, and, as there are large tracts of land in New Zealand destitute of native grasses, the depredations of these insects became a serious matter to those settlers who had stock to feed and who were relying on the English grass to feed it. It was all the more serious because the insects were without any natural check, the native birds which had kept them in subjection before the advent of the white man having been either killed or driven from the vicinity of the homesteads. So the beetles continued to make merry, to marry, and to multiply. In a corresponding ratio the grass continued to fade, to wither, and to die.

Then came the English starling, and so voraciously did it feed on the larvæ that soon all was green again.

A case similar to the foregoing occurred about five years ago in an inland district of Australia, where, owing to the ruthless destruction of wild bird life, grubs took possession of the land, and, eating out the grass by the roots, transformed what had been a rich pastural country into an unprofitable waste.

Without the aid of birds grass could not be grown. The grub of a single species of beetle, if unchecked in its multiplication, could destroy all the roots in our meadows; or any one of the several species of cutworms, if its reproduction was not restrained by birds, might be sufficient to destroy all the verdure above ground.

HAWKS AND OWLS.

The injury to trees, crops, and grass by insects is not the only evil that threatens man as a sequence to the destruction of birds. Rapacious birds hold a chief place among the forces which are appointed to hold in check small rodents, which breed rapidly, and unless kept within bounds are exceedingly destructive. Yet, notwithstanding

the unanimous testimony of careful students of birds and their food habits to the effect that almost all hawks and owls are beneficial, a widespread prejudice still exists against them. They are slain as relentlessly as if they were enemies instead of friends of the farmer.

The destructive habits of the small rodents, which are the natural prey of hawks and owls, are much the same all the world round. They do an incalculable amount of damage to standing corn, to corn in the stook or when stacked, to grain, to root crops when growing or when piled on the ground or stored in pits, to orchards and forest trees, to the roots of clover and other grasses, to ground-growing fruit, and to gardens, both flower and vegetable. In addition to this list of crimes, certain rodents are active agents in carrying and disseminating the germs of plague and other diseases.

Here in England—though on account of their small size and secretive habits they are often undiscerned by man's dull eyes—they swarm in such numbers in the fields and hedgerows that the damage they do must prove a steady drain on the resources of the farmer.

The number of small rodents eaten by the rapacious birds is almost as remarkable in proportion to their size as is the number of insects eaten by small insectivorous birds. During the summer of 1890 a pair of barn owls occupied a tower in a building at Washington. After their departure there were found in the regurgitated pellets, with which the floor was strewn, 454 skulls of small rodents.

The young of hawks and owls remain a long time in the nest, and require a great quantity of food. During this period the resources of the parents must be taxed excessively in the effort to satisfy the hunger cravings of their offspring, and it is not to be wondered at if some individuals are forced occasionally to snap up a chicken. But what is the worth of the chicken, or of the young pheasant, occasionally taken, compared with the hundreds of thousands of pounds' worth of damage that is wrought in the orchards and fields by rodents that hawks and owls, had they been spared, would have fed upon for the maintenance of their species?

In 1885 the Legislature of Pennsylvania passed an act, known as the " scalp act," which provided a bounty of 50 cents each on hawks and owls killed within the State limits, and a fee of 20 cents to the notary taking the affidavit. As the result of this act $90,000 was paid in bounties during the year and a half subsequent to the passage of the act. An irruption of small rodents followed and did damage to the agricultural interests of the State amounting to $3,850,000. And even these figures, enormous as they are, do not represent the entire loss. Years must elapse before the balance of nature, which was destroyed, can be restored.

In Montana the destruction of hawks and owls was so complete that rodents, freed from the pressure of their natural check, became

as one of the plagues of the Book of Exodus. Then the legislature passed a law offering bounties for the destruction of these four-footed pests. During six months of 1887 such large sums were paid out in bounties for the destruction of small rodents—a work that the hawks and owls had previously done free of charge—that a special session of the legislature was called to repeal the act, lest it should bankrupt the State.

In 1907 Nevada went through a very trying experience with mice, while Utah, Wyoming, California, and several States farther east have all had occasion to bitterly rue the day that they shot their hawks and owls.

But the destruction of small rodents is not the only function of rapacious birds in the economy of nature. Several species are voracious insect feeders. Nor is this all. It is well known that when small insectivorous birds increase abnormally in numbers they, too, became a pest. Hawks and owls materially assist those other agencies of nature which act as a check on the undue increase of small birds. If rapacious birds were rigorously protected in this country we should have fewer complaints of the damage done by sparrows.

Birds of prey, if unmolested, not only prevent the overproduction of small birds, but they also confer a salutory benefit on each species on which they prey by checking the propagation of weakness or disease by killing off the sickly and most unfit individuals, for these are the most easily seen and the most readily captured. This is particularly true of game fowl, and one of the most plausible hypotheses explanatory of the occasional outbreaks of disease among grouse has been the removal of this corrective by ignorant gamekeepers.

Yet it is my belief that nothing but a miracle will ever make these men see the error of their ways.

Some years ago, when lying in the sweet-smelling heather on a mountain side in Scotland, I pleaded for the life of the hawk before one of its executioners. The gamekeeper listened in silence until my address to the jury, so to speak, was concluded. Then he said, " Ye've a cold i' the heid." I did not see the relevancy of this remark, but I nodded assent. After a pause, he added, " Ah, weel; ye canna complain. The cold aye attacks the weakest place first."

Kaffirs say, " He who kills a hawk must be put to death."

THE ECONOMIC VALUE OF THE WHITE HERON.

The destruction of the white heron for its scapular plumes has robbed half the world of a bird which is most useful to man. It never touches grain, but feeds solely near water and over damp ground, the breeding places of innumerable batrachians, small crustaceans, and pestiferous insects, all of which directly or indirectly injuriously affect crops in the neighborhood. The presence of the

white heron in the rice fields, for instance, is distinctly beneficial to the farmer, and rice is one of the most extensively grown crops of India and of China.

In Australia the slaughter of this and other wading birds for their plumage is causing in that country a decline in its fish resources. It is the destruction of these birds which has led to the ever-increasing multitudes of crustaceans which destroy the fish spawn and the young fish hatching out in the Coorong and in the lakes at the Murray Mouth.

In his report on Egypt for the year 1912 Lord Kitchener stated that the indiscriminate destruction of bird life had allowed an enormous increase of insect pests, steps for the combating of which were to be taken. Lord Kitchener knew that in spite of the improved methods of fighting insects there was only one step that he could take that would be effective. A Khedivial decree was issued forbidding the catching or killing of, or taking the eggs of, Egypt's insectivorous birds. In issuing this decree, two things were prominent in Lord Kitchener's thoughts—the destruction of the egret for its plumes, and the fact that in the valley of the Nile this bird is one of nature's checks on the cotton worm.

White herons consume many flies, as well as the larvæ of insects in water. This fact is well known to those who have watched the habits of oxen and buffalo in Asia or Egypt. There the smaller white herons—the paddy birds of India—live with the oxen or the buffaloes, and pick the flies or the ticks from their bodies.

The late George Grenfell noted once on the Congo how a dying white heron, which he had shot and put into his canoe, roused itself, even on the approach of death, to snap at the tsetse flies which were settling on his boatman's legs.

VALUE OF BIRDS TO LIVE STOCK.

The injury done to domestic animals by biting and parasitic insects is very great. Herds of cattle are often stampeded by these tormenting creatures, which carry disease and death among them. Another great affliction is the warble, which is a small tumor produced by the larva of the gadfly on the backs of cattle, and the constant irritation of which causes considerable depreciation in the value of hides, besides a lessened quantity and poorer quality of beef.

Horses, sheep, and other farm animals are subject to the attacks of similar parasites and other persecuting insect foes.

If it were not for the services the bird renders in alighting on animals in search of these parasites, or in catching the flies on the wing, or in eating them in the embryo state, man would be unable to keep his live stock.

More than this, man himself would be unable to inhabit many places on the earth which he now cultivates, or where he carries on other lucrative industries.

SHORE BIRDS AND DISEASE.

Deadly maladies are carried about by the myriads of mosquitoes and flies that abound on the coasts of tropical and subtropical countries. Yet the shore birds, which render invaluable services to man by destroying these venomous pests, are thoughtlessly killed by him in countless thousands.

To his honor, be it said, one of the first acts of Mr. Wilson when he became President of the United States was to issue an Executive order prohibiting, under heavy penalties for infraction, the destruction of any wild bird in the Canal Zone.

GAME BIRDS AS WEED DESTROYERS.

Unquestionably weeds serve a useful purpose in nature, but that purpose is not the occupation of cultivated land. Without check they would speedily choke all grain to death.

Constant use of harrows and hoes will do much on farm lands and in gardens to keep down weeds, but as most earth is full of weed seed, which retains its vitality for years, the life of the tiller of the soil is one continuous struggle against these troublesome plants. In this battle the bird is of great assistance, for the number of weed seeds eaten by birds on cultivated land must be beyond any assignable quantity.

Game birds generally are the greatest eaters of weed seeds. They are also useful to man in several other ways. Not only do they devour mature locusts, but they scratch up and eat the eggs. They also consume in large quantities termites and other equally pernicious insects. The reckless shooting of game birds is to be deprecated. They are of far more use alive than in swelling the bag of the sportsman.

The quail is perhaps the greatest weed destroyer of all the game birds. It is doubtful, indeed, if the quail is not more useful to man than any other bird. It is very nearly wholly beneficial. During spring and summer it feeds on many of the most destructive of insects, and in autumn and winter it eats an enormous amount of seeds of many harmful weeds.

The report of the United States Biological Survey says:

It is reasonable to suppose that in the States of Virginia and North Carolina from September 1 to April 30 there were four quail to each square mile of land. The crop of each bird holds half an ounce of seed and is filled twice a day. Since at each of these two daily meals harmful weed seeds constitute at least half the contents of the crop, a half ounce daily is consumed by each bird. On this basis the total consumption of harmful weed seeds by quail from September to April in Virginia and North Carolina amounts to 1,341 tons. As destructive insects form about one-third of the bird's food from June to August, quail consume 341 tons of these pests in these States within those two months.

But perhaps the most valuable service that quail render the people of the United States is the greedy way in which—and they stand almost alone among birds in this particular taste—they eat the evil-smelling potato bug, or, as we call it, the Colorado beetle.

In addition to this inestimable service it is partially due to this bird that the cotton boll weevil has not swept over the entire cotton belt of America, bringing ruin to thousands of human beings on both sides of the Atlantic.

THE BIRD AS A SCAVENGER.

The fishing population of these islands has declared war on the gulls, and is demanding the withdrawal of certain species from the list of protected birds, on account of the damage they are alleged to do to the fishing industry. People who believe fishermen's tales are apt to be duped and led into repeated errors. The gull is a surface feeder. It may occasionally levy toll on useful fish, but to say that it does any appreciable injury to the fishing business is absurd.

On the other hand, the presence of the gull is essential to man's health. While the bird fulfills many useful minor offices—such as destroying larvæ in land along the seaboard and in eating enemies of fish that are exposed during low tide—its chief function in the economy of nature is that of scavenger of the harbors and of the littoral, just as vultures are the scavengers of the mainland. The wholesale destruction of gulls for their plumage in Yucatan was followed by a great increase of human mortality among the inhabitants of the coast, which mortality was irrefutably due to the loss of the birds that had kept the harbors and bays free from the decaying matter which the sea is constantly casting ashore.

I wonder if these men who wish the gull destroyed ever give a thought to what would happen to their own smelling villages if this bird was not present to eat the refuse they throw about? Or, again, if they ever reflect on that feeling of relief they experience when in thick weather they hear, through the fog, the clamor of these feathered bell buoys, warning them that they are nearing rock or bar?

THE BIRD AS A GUANO PRODUCER.

Now that I am on the subject of pelagic birds, I will speak of their value as guano producers.

Undoubtedly the present enormous trade in fertilizers owes its origin to the bird, for the fertilizing properties of the phosphoric acid and nitrogen contained in fish was not recognized until guano—which is the excrement of sea birds mixed with fish—became a stimulus to intensive agriculture.

The value of guano as a fertilizer was known to the people of Peru in the time of the Incas, though the nineteenth century had dawned

before the information was carried to Europe by Humboldt. Under the rule of the monarchs of old Peru the birds were rigorously protected and the guano deposits carefully guarded. Three centuries later these protective measures materialized in a source of revenue to the country. Generation after generation of sea birds had placed on their breeding grounds deposits of guano which, in 1853, were estimated by the Peruvian authorities to be worth $620,000,000.

It is our pleasure to think of the Incas as barbarians and to look upon their times as dark and rude. In our own enlightened age man kills at one fell swoop over a quarter of a million sea birds on an island valuable for its guano deposits.

VALUE OF WILD BIRD LIFE AS A FOOD SUPPLY.

Under certain conditions wild bird life is invaluable to man as a food supply. The pioneer must—at any rate, at the commencement of his farming operations—live in great part on the wild products of the earth. In days gone by the forerunner of civilization could confidently rely on his gun to keep his larder constantly stocked with edible birds. Now, in many parts of the world, he is confronted with an alarming scarcity of this kind of food. The great straits to which the pioneer of the future will be reduced on account of the present-day slaughter of valuable bird life is foreshadowed by what is happening to-day in Hudson Bay. Fifty years ago the number of wild duck in North America was beyond computation. But man could not slay this bird fast enough to glut his blood lust. Sportsmen, professional hunters, and agents of the millinery interest smote them by the million. Such blind and wanton butchery could have but one result. Ducks are now so scarce along the west coast of Hudson Bay, where there are no moose, caribou are scarce, and the fishing is poor, that the people living there, who had always depended on the ducks they could pack away in the autumn, find it difficult to get sufficient food to carry them through the winter.

THE ÆSTHETIC AND SENTIMENTAL VALUE OF BIRDS.

Omitting all mention of various other material benefits which birds confer on man, I will, before concluding, notice briefly their æsthetic and sentimental values.

Bird life is the part of the creation in which nature has done more in the way of bestowing mental benefactions on man than in any other of her works. Unconsciously received, yet born of it, there is a spiritual teaching, an uplifting influence, in the study of birds which tends to make a man act more constantly from principle, which tends to give a new and a more wholesome tone to his whole life.

The companionship of birds affords a happiness as pure, perhaps, and as permanently exquisite as man in his present state of being can possibly enjoy. Never came purer joy into my life than when, rising

at dawn from my couch of fern, I heard the approach of the coming day heralded by a chorus of glad bird voices. Never have I experienced emotions which have so lastingly impressed my mind as when, in the inexpressible mystery of the darkened forest, with the stars drifting over, I listened to the sublime notes of some feathered psalmist, itself in night invisible.

The world itself is but an outline sketch; it is the birds which fill in the details and complete the picture. Towered vapors of the summer firmament hang on the wall of the sky against a setting of immutable blue; the trees are motionless; the glassy waters of the lake too idle to curve and break upon the shore. Nothing speaks of life or action. Suddenly, hitherto unseen in leafy tracery, a bird rushes out and up into the air, telling the sunshine all its joy. One can almost hear the mechanism start. The world begins to live and move. What artist is there who does not know this? Even when painting either of the two most majestic scenes on the earth—the ocean or the Himalayas—he adds this stimulating power to his canvas.

To turn from the palette to the pen, what poet is there who has not been inspired by birds? From the background of my memory a thousand instances of such inspiration come leaping forth. Shelley, Coleridge, and Longfellow, to mention three only of our singers, have been each rendered immortal in virtue of the power exerted on their minds by the bird. "To a Skylark," "The Ancient Mariner," and "The Birds of Killingworth" are poems that are imperishable.

The Mexicans felt the poetry when they looked upon the humming-birds as emblems of the soul, as the Greeks regarded the butterfly, and held that the spirits of their warriors who had died in the defense of their religion were transformed into these exquisite creatures in the mansion of the sun.

Earth holds no joy to the eye more sweet than the sight of one of these living gems as it flits to and fro with the shrillest vibration of swiftly beating wings, hovers for an instant in the shade of a pendulous blossom, shoots out again into the sunshine, darts away after an insect, wheels round and round in sheer exuberance of spirit, returns to sip at the nectared cup, then flashes up again, glittering with all the colors of the prism, into its home in the air.

Was all this beauty for no purpose but for the gratification of a passing fashion? Is man constitutionally unable to realize that in the beauty of these feathered jewels there is a value greater than the value that is entered in a ledger? Children gather flowers of the field, and, presently, their fleeting fancy sated, toss them aside to wither and die. But the seeds, the roots, remain. The daisy will bloom another year; the cowslip will stain the meadows yellow as of yore; but these blossoms of the air will never bloom again. Once gone, they are gone forever.

CONCLUSION.

Birds unquestionably are one of man's most valuable possessions, yet it is just the possession on which he sets the least value.

Wherever there are birds whose plumage is suitable for millinery, there will the cruel and rapacious agents of the feather dealers be found engaged in orgies of wasteful destruction. Wherever there are birds that are classed as " game," there hastens the market hunter to kill, kill, kill, so long as any salable thing remains to be killed. Wherever there are species that have been harried by man to the brink of extinction, there will be the collector also, anxious to obtain the last lingering representatives of a race before his rival gets a chance to do so. Wherever there are birds whose eggs are valuable, there hurries the egg collector to destroy not only the embryonic life, but often the mature life as well by shooting the bird that laid the egg for the purpose of identification. Wherever in the wild places of the earth there are birds which are considered to be " good sport," there saunters that vandal of creation, the hunter of means and leisure, to expend on the most beautiful and the most harmless works of nature his instinctive desire to kill.

It is the nature of infamies, as well as of disease whose progress is not checked, to daily grow worse; and if the present-day wasteful and depraved practice of denuding the world of one of its most valuable natural resources is not checked, there will be wrought a mischief, a universal disaster, more awful in its results than words can express.

LONDON, 1914.

EXPERIMENTS IN FEEDING HUMMING BIRDS DURING SEVEN SUMMERS.[1]

By ALTHEA R. SHERMAN.

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The experiments herein described were begun without intending them to bear upon the question of the food naturally sought by the ruby-throated humming bird (*Archilochus colubris*); the original aim of the feeding was to attract the humming birds about the yard in the hope that some time they would remain to nest there. The experiments have been conducted on independent lines without knowledge of any similar work that was being done by others until the autumn of 1912, except in one instance, where special acknowledgments are due Miss Caroline G. Soule, of Brookline, Mass., who in Bird Lore for October, 1900, described her success in feeding humming birds from a vial, which she had placed in the heart of an artificial trumpet flower made from Whatman paper and painted with water colors. This suggestion of using artificial flowers was taken, but more durable ones were made from white oilcloth, their edges were stiffened with one strand of wire taken from picture cord, and they were carefully painted with oil colors, the first to represent a nasturtium and the second a tiger lily.

In August of 1907 upon the appearance of a humming bird about our flowers the artificial nasturtium, tacked to a stick, was placed near a clump of blooming phlox, and its bottle was filled with a sirup made of granulated sugar dissolved in water. The next day a female rubythroat was seen searching the depths of tiger lilies that grew north of the house; as she flew to the east of the house she was instantly followed, and was seen drinking from the artificial flower for the space of about a minute, after which she flew to a rosebush, wiped her bill, and rested a brief time before flying away. This was about noon. She returned at intervals of about a half hour for the next three hours, then at 3.10 o'clock she came back to search quite thoroughly the phlox blossoms, this being the first time she had paid

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any attention to them after finding the sirup. Ten minutes later she drank deeply from the bottle and was seen no more that day.

In this way began the feeding of the ruby-throated humming birds, which has been continued each summer since 1907 with a varying number of birds. The first season it appeared that but a single bird found the bottled sweets. Perhaps it was the same bird that came the following summer, and was not joined by a second humming bird until the latter part of August. In 1909 the number was gradually augmented until seven of these birds were present together. The following year there were days when again seven came at one time; since then four has been the largest number seen together.

The days and weeks are calm and quiet ones when a single bird has the bottles to herself. More or less fighting ensues as soon as another bird comes on the scene, and the tumult of battle increases with each new arrival until the presence of six or seven of these tiny belligerents makes the front yard appear like the staging of a ballet. With clashing sounds and continuous squeaking cries they chase each other about, often swinging back and forth in an arc of a circle with a sort of pendulum-like motion. Sometimes they clinch and fall to the earth, where the struggle is continued for many seconds. So jealous are they lest others share the sirup that they seem more anxious to fight than to drink. When seven are present they are very difficult to count, and appear to be threefold that number. We have read accounts of 40 or 100 humming birds hovering about a tree or bush. Clearly these numbers must have been estimates, probably large ones, too, anyone must believe who has made sure that only seven birds have created the maze of wonderful and beautiful motion in which there seemed to be a dozen or a score of participants.

The number of bottles in use has been sufficient on most days to satisfy the needs of all the humming birds present. Each new bottle has been added by way of an experiment. The first one was placed in an artificial flower painted to imitate a nasturtium, mainly yellow in color; the second flower in form and color closely resembled a tiger lily. The experiment with the yellow and the red flowers was to test a supposedly erroneous theory which had been published to the effect that humming birds show a preference for red flowers. In further proof of the fallacy of this statement the third flower, shaped like the nasturtium, was painted green, and was placed in a bed of green plants which at that time bore no blossoms. It was pronounced by other people to be " exactly the color of the surrounding foliage." It was staked out and filled on August 5, 1909, when no humming bird was in sight, but in about 10 minutes some of the species had come, and 15 minutes later one was drinking from the bottle in this green flower.

It was then suggested by my sister, Dr. E. Amelia Sherman, that I try a bottle without an encircling flower. The problem of supporting a bottle without an artificial flower was solved in this way: The bottle was incased in a piece of unbleached muslin, enough of the cloth extending beyond the bottom of the bottle to allow the tacking of it to a stick. The support of the bottle in a position slightly up from the horizontal was furnished by a piece of leather with a hole in it through which the bottle was thrust, and the leather was then nailed to the stick. In this arrangement the most vivid imagination can find no suggestion of a flower. It was put out on August 8, and in 43 minutes a humming bird was drinking from it. The bottle was then moved from proximity to the artificial nasturtium and tiger lily, and a humming bird found it in its new location in 32 minutes. This place about 8 feet from the artificial flowers has been its position in the four succeeding summers. In July, 1911, two more flowerless bottles were added to the group, making six in all. For convenience in referring to them the flowerless bottles will be called by numbers 4, 5, and 6.

Bottle No. 4 had not been long in use before it was noted that the humming birds showed preference for it, while the nasturtium was sought least of all. This seemed due to the deep insetting of the bottle in the flower, which caused the birds to brush against its lower leaves, an unpleasant experience when sticky sirup adhered to it. For this reason the filling of the nasturtium was sometimes omitted for several days, whereupon the humming birds soon ceased to visit it, although drinking regularly from the tiger lily a few inches away. When the filling was resumed the birds returned to it as they had been accustomed.

In the fourth season of experiments the bottle held by the green flower was put out when the others were, but was not filled for six weeks. During that time humming birds were present and drinking on 23 days. It is safe to say that they were seen drinking fully 400 times from the other bottles, but never once were they seen to approach the green flower. The first morning it was filled four of them were about the yard and one drank from this flower two minutes after the filling. The following year (1911) after dark on July 14 the green-flower bottle was set in its bed of green and was left empty for a few days. About noon on the 17th one of the rubythroats visited it, thrusting in her bill; the bottle was then filled for the first time that year, and in a half minute a bird was drinking from it. To this is added a transcript from my journal bearing date of July 17, 1912: "About 9 a. m. before I had put out any sirup a humming bird was dashing from bottle to bottle and tried the green-flower one. It was bent over in the green foliage, and certainly has had no sirup

in it for six weeks or longer. I filled it after I saw the bird visit it, and she came again to drink."

The new bottles No. 5 and No. 6, covered like No. 4 with white muslin and nailed to a weather-beaten fence picket, were put out after dark on July 23, 1911, but neither was filled for one week. The next morning about 8 o'clock a humming bird was searching one of these bottles for suspected sweets; four such visits were noted in one day and on several other occasions. At the end of the week the filling of No. 5 began, but no sirup was put in No. 6 for two years. During these years a record was kept of each time a humming bird was seen to visit and search this unfilled bottle, and the total number was 15, in addition to those visits already mentioned.

Thus far this writing has been confined to a description of the things seen; no theories have been advanced, no deductions have been made, no hypotheses have been carried to their logical conclusion. The first deduction offered is that at the beginning of the experiments, in 1907, the artificial nasturtium may have led the humming bird to explore its depths, and, finding its contents to her taste, she returned to it. Other birds may have found the sirup there in the same way, yet it seems more likely that most of them were led to the bottles by seeing another drinking. This probably was the case with the catbirds that have drunk from the bottles on several occasions, although they have found it an inconvenient performance. The same may be true of a pair of chickadees that drank as long as they remained with us. They clung to the stiff leaves of the tiger lily and found no difficulty in the way of drinking. Only one humming bird learned to perch on this flower and drink from it while standing. From the earlier experiments it was suspected that the humming birds found the sirup through some sense, rather than stumbling upon it by chance or through imitation, but several things disprove such a supposition. The principal one is that migrants passing through the yard in the spring, but more especially in the fall, fail to find the sirup. That these migrants can be recognized as such by their behavior will be shown further on.

The 25 or more visits paid to bottles No. 5 and No. 6 before they were filled for the first time show that the birds recognized them as receptacles for their food, though they were new bottles occupying new locations. To make sure that the birds should not be attracted to them by seeing me stake the pickets out, this work was done after dark. The first summer that No. 6 was out, frequent pretenses of filling it were made in sight of the birds, but no response followed. The next summer no such pretenses were made, yet a humming bird was seen to search this unfilled bottle on May 12 and 31, twice on June 1, on July 21 and 26, on August 4, 7, 12, 23, and 26.

One is led to wonder if the Homeric gods on high Olympus were more deeply stirred by the appearance among them of the youthful Ganymede bearing cups of nectar than are the humming birds at sight of their cupbearer. When several of them are present the wildest confusion reigns. Possibly not one of them is in sight when the door is passed, yet instantly the air seems filled with them; some swinging back and forth in the air, squeaking and fighting, or darting from bottle to bottle thrusting in their bills as they pass, while an overbold one will buzz about my head, sometimes coming under the porch in her zeal for the meeting; but the timorous ones fly from their perches into sight over the bottles, then back into a bush. Some one of these types of behavior marks the bird boarder from the migrant. The latter pays no attention to cupbearer or bottle, but diligently searches each bunch of blossoms. For two or three weeks after the drinking birds have left there is occasionally a migrant among the natural flowers. The bottles are full of sirup, but it passes them unheedfully.

Habits seem to change when steady drinking is practiced, but in the case of the birds the habit does not appear to be a harmful one. At once she ceases to search the flowers and, like the typical summer boarder, she sits and waits for the food to be served. Each bird appears to have her favorite perch, a dead twig of syringa or lilac bushes on the north, or on the south in one of the snowball bushes; the telephone wires on either side of the street offer acceptable waiting places at times. Not infrequently I have been intent upon other duties about the yard and looking up have found a rubythroat perched directly overhead, her bright eyes seeming to say "I want to be fed." So complete appears the cessation of the search for other food that it led to the keeping of a full record for the past three years of every time one of these birds has been seen catching insects or searching the natural flowers for food. Most of these instances noted were, if the whole truth could be learned, probably, cases of strangers just arrived within our gates that had not yet acquired the drinking habit.

In 1911 the drinking birds were about our place on 43 days. During that time on only four occasions was a humming bird seen catching insects or probing the flowers. A large number of plants called "Star of Bethlehem" had been raised, these flowers in previous summers having proved a great attraction to the rubythroat in the yard of a friend living 2 miles distant; but our drinking birds were never seen to visit these flowers. After their departure strange humming birds searched them thoroughly, as well as the phlox, tiger lilies, sweet peas, nasturtiums, and clover. These strangers were present on 12 days. In 1912 the drinkers were with us on 77 days, and were

seen but 10 times seeking other food than sirup. In 1913 for 49 days the drinking birds imbibed, and on nine occasions a humming bird was seen gathering food elsewhere. In the 169 days that make the grand total for the three summers, the rubythroats were seen drinking sirup between one and two thousand times; they were seen collecting food away from the bottles 23 times; but one can not be positive that insect food was always taken then. Never for an instant was one of these birds in captivity, and there was the utmost freedom for it in choice of food.

This choice of a sugar diet, together with the large amount consumed, caused surprise, and soon called forth the estimate that a humming bird would eat a teaspoonful of sugar in one day. Some method of testing this estimate was sought, resulting in a plan for putting the bottles beyond the reach of the ants that swarmed about them. The stick that supported the artificial nasturtium and tiger lily was nailed to a block of wood which was submerged in a flowerpot filled with water. For a short time this arrangement served very well, until leaves and flower petals fell in, forming rafts upon which the ants were able to cross. No myrmecologist was at hand to suggest a remedy, but at last the aversion of ants to kerosene was recalled, and the water was covered with a film of kerosene, which effectually debarred them. Nevertheless, one day the ants were found taking the sirup as of old. An examination of existing conditions showed that a grass stem had lodged against the supporting stick, forming a bridge over which these wise little creatures were busily passing to and fro. Except when the bottles were isolated in this manner ants of various sizes and different colors fed constantly on the sirup, often crowding a bottle to its very mouth, but this did not prevent the birds from drinking. I am not prepared to say that they never took an ant as food, but I have stood as closely as is possible to a bottle while a humming bird was drinking from it, and none was taken at such times. When a new bottle was placed, or the old ones were set out in the spring and filled, it took from one to two days for the ants to find the sirup. A small red species generally, if not always, was the ant to make the discovery, the fruits of which it enjoyed for a very brief season, a large black ant soon taking possession and holding the spoils for the rest of the summer.

The bottles, having been removed from the encroachments of the ants, were ready for the first test. One bird being the sole boarder at that time, a level teaspoonful of sugar dissolved in water was consumed by her daily. In time, two, three, four, and five humming birds having joined her, the quantity of sugar was increased accordingly, a spoonful or two being added to offset any possible waste. In this way more than a pound of sugar was eaten in 20 days, or, to be more exact, three cupfuls, weighing 9,252 grains, which made an

average of 462 grains per day. This for the six birds frequently counted as present confirmed the first rough estimate of a teaspoonful of sugar daily for each bird.

Another method of estimating the amount eaten was devised. On several days the sugar and the water were carefully measured and weighed, then weighed and measured again, after which the sirup resulting from their combination was also measured and weighed, until I felt confident that in a dram of the thinnest sirup served there were 40 grains of sugar, or two-thirds of a gram to every drop. But the sirup usually used was considerably richer than this, easily containing a grain of sugar in every drop; but it seems best in giving the estimates to keep them to the weakest grade of sirup ever served.

In making the test a dram of sirup was measured in a glass graduate, and bottle No. 4 was filled. This was always done in the morning, when the bottle had been emptied by ants. A waiting humming bird came and took her breakfast, after which the residue of sirup was poured back into the graduate, the bottle being thoroughly drained. Possibly a drop still adhered to the bottle, but the number of minims now in the graduate subtracted from 60 must have given very nearly the amount drunk by the humming bird. In two summers a number of these tests were made. A bird took for her breakfast from 8 to 20 minims, the average being 15. Using the low estimate of two-thirds of a grain of sugar to each drop, the average breakfast held 10 grains of sugar. A better comprehension of the size of that meal may be gained by remembering that two large navy beans or one medium-sized lima bean also weigh 10 grains. Breakfast and supper were the rubythroats' heaviest meals, but there were many luncheons between them. By reckoning eight to nine such meals daily (and beyond doubt there were that number), we reach again the first estimate of 70 to 90 grains of sugar as the daily ration. About this amount of sugar is held by a common teaspoon when level full; such a spoon will hold from 110 to 120 minims of water, whereas one of those heirlooms, a grandmother's teaspoon. is the measure of the standard teaspoonful of 60 minims. Referring, then, to the standard measure, the bird would be said to eat two teaspoonfuls of sugar daily. An ordinary cube of loaf sugar contains the equivalent of this amount.

Reflecting upon the bulk consumed by so small a creature, one naturally desires to know the weight of a humming bird. A little boy brought to us the body of a male that had been shut into a machine shed, where its death may have resulted from starvation. Its weight was 33 grains. Naturalists in early days were vexed by the same question, as is shown by a quotation given by Mr. Ridgway

in his book on humming birds. It is from Philosophical Transactions, 1693, by Nehemiah Grew, who wrote: "I did weigh one (in those parts) as soon as ever it was killed whose weight was the tenth part of an ounce avoirdupois." From these weights one makes the deduction that our humming birds are accustomed to eat of sugar twice their own weight daily. If human adults ate of sugar proportional amounts there would be required nearly 300 pounds of this saccharine food daily for the average person.

No attempt has been made to tame the birds that came to drink, yet one, perhaps two of them, became bold enough to drink when a bottle was being filled; while she thrust her bill into the empty receptacle a spoonful of sirup was frequently held touching the mouth of the bottle, but she did not learn to drink from the spoon. While drinking the tongue was extended about a quarter of an inch beyond the tip of the bill, and two or three drops were sipped before the bill was withdrawn. Once 15 drops were taken with three insertions of the bill, and at another time the bird drank without the withdrawal of her bill for about the duration of a minute. At such times the bottle was free from ants; probably they were present when the drinking was done with numerous sips. Often a bird preferred to take her breakfast in courses, perching on a near-by dead twig for a minute or two between drinks.

During two of the seasons it was thought that some of the birds roosted on our place, appearing as they did very early, and making a long day for feasting and fighting. In other years the birds were seen to fly eastward at night and their morning arrivals were not so early. One June morning a bird was ready for her breakfast at 4 o'clock, and took her last drink at night just before the clock struck 8. On some August days there are records of their presence at break of day; in one case it was 38 minutes before sunrise. They usually lingered a short time after sundown, drinking long and deeply before taking their evening departure.

The conviction that the same birds were returning to us summer after summer began to be felt at the beginning of the fourth season. On May 26 of that year the first humming bird appeared on the place. The next day the flowerless bottle No. 4 was put out, and in a few hours a bird was drinking from it. For the next three weeks she was seen drinking from this bottle on every day except two, but not in the middle of the day; then for two weeks she was missed, returning again on the 1st of July.

The history of the fifth season was similar. Humming birds having been seen on May 22 bottle No. 4 was staked out and filled for a few days. No bird coming to drink, the bottle filling had been discontinued, when on June 6 a humming bird on suspending wings was seen searching this bottle. Not finding sirup in it she flew to the

spot always occupied by the flowerpot holding the artificial flowers when they were in place. Over this vacant spot she hovered an instant before flying away. On a few other June days a bird of this species was present and on the 17th one was seen drinking, but her steady summer boarding did not begin until July 9. In the sixth spring the species arrived earlier than usual. No bottles were out on May 7 when a humming bird was seen hovering over the customary place for the artificial flowers. As quickly as possible these flowers were put out, but before they could be filled the bird was thrusting her bill into the tiger lily. She came to drink on most of the days thereafter until June 9, also June 14, 15, and 24, and on July 1 and 2; but it was not until July 16 that she came for constant drinking.

These dry and dull details have been given in full because two theories were based on them. That the birds of former years have returned to be fed seems unquestionable from their searching at once flowerless bottle No. 4 and from the other evidences offered. That the birds came in May and at intervals in June and July before becoming steady boarders about the middle of July, seems to indicate that they nested 2 or 3 miles away, too far for daily trips after incubation began. The supposition that these nestings were in the woods is founded on the fact that in leaving the birds flew in that direction, also because they were never found about the trees of the four farmyards that intervene between our place and the woods. That in two summers a mother rubythroat returned with her daughter was suggested by seeing on several occasions two birds drinking together from one bottle, a phenomenon that needs explanation when we consider the pugnacious disposition usually exhibited by one drinker toward another.

In further confirmation of the foregoing is the history of the feeding in 1913. Bottles No. 4 and No. 6 were set out on April 30. For two months and a half no humming bird visited them. It chanced on July 14 that the stick support of No. 4 was lying on the ground, leaving only No. 6 in position, when my sister saw a humming bird thrusting her bill into it. She hastened to fill this bottle, which was the first time it had ever been filled, and it lacked but eight days of two full years since it was first set out. Six days later I was in the orchard a hundred feet or more distant from the bottles, when a humming bird flew toward me and buzzed about my head as do no other birds except those that are fed. With greatly accelerated pulse I hurried to the house and filled the bottles. In exactly two minutes the humming bird was drinking from one of them; this was the first drinking witnessed in that year. It was one of my most thrilling experiences in bird study. Two marvelously long journeys of from one to two thousand miles each had this small sprite taken

since last she had drunk from the bottles, yet she had not forgotten them, nor the one that fed her.   She was quite prone to remind either of us when the bottles were empty by flying about our heads, wherever she chanced to find us, whether in the yard or in the street.   Once having been long neglected she nearly flew into my face as I opened the barn door to step out.

The last experiment made was that of flavoring one of the bottles of sirup with vanilla, and later with extract of lemon, to see if the birds showed preference for the plain sirup or for the flavored.   Both kinds were served at the same time, and of both the birds drank, showing no choice that could be detected.

It may already have been surmised from the gender of the pronoun used that it is the female only of this species that has the " sweet tooth."   Never once in the seven summers has a male rubythroat been seen near a bottle.   The drinking birds have been examined long and critically, with binocular and without, in order to detect on some of the birds the identification marks of the young males, but without success; moreover, had young males been present they, too, would have been apt to return in later years.   This absence of the males led to noting their scarcity in general, and to recording in notebook when and where a male at any time was seen.   The entire number seen in the past five years has been six on our place and six elsewhere.   It is impossible to do more than estimate the number of females that have been seen; but when it is remembered that on several days in two summers seven have been in sight at one time, it does not appear to be an overestimate to place their number at twelve or fifteen for each year or six times more of them than of the males.

The simple experiments herein described are such that they may be tried by any one having a yard frequented by the rubythroat.   If any one doubts that the female of this species will choose a saccharine diet, when it is available, let him continue the tests until convinced beyond cavil or a doubt.   It is especially desirable that the experiments be made in proximity to the nesting birds in order to see if the mother will feed sirup to her nestlings.   Sometimes our catbirds and brown thrashers have come into the porch to the cat's plate and taken his bread and milk for their nestlings.   Upon this hint for needed aid I have put bread soaked in milk on the fence railing for them, and they have taken it also.   It is reasonable to believe that in like manner sweet benefactions proffered to a hardworking humming bird mother might be acceptable to her and shared by her with her nestlings.

WHAT THE AMERICAN BIRD BANDING ASSOCIATION HAS ACCOMPLISHED DURING 1912.[1]

By Howard H. Cleaves.[2]

[With 2 plates.]

Since it is obvious that this report will fall into the hands of many who are not cognizant of the facts relating to the origin, growth, and present status of the bird banding movement in America, it might not be amiss to devote a brief space at the outset to a review of that phase of the subject. The mystery of bird migration has tickled and agitated the lay mind and engaged the attention of the ornithologist for we know not how long, and although much has beer ascertained by field observers with regard to dates of arrival and departure at given points of the majority of migratory species, practically nothing is known of the movements of individual birds. Even Audubon became interested in this problem, for we read that he placed silver wire rings about the tarsi of a brood of young Phœbes and was rewarded the following year by discovering two of these birds nesting in the same vicinity. Whether through reading of this interesting incident or hearing of the splendid efforts put forth by certain Europeans who began banding birds as early as 1899, or by reason of a spontaneous desire to investigate, it would be difficult to tell, but the fact remains that not later than 1902 individual experimenters in this country engaged themselves in earnest and comparatively extensive efforts to cast light on the wanderings of birds by the use of inscribed metal bands or rings.

Not until 1908, however, did anything approaching a concerted bird banding movement develop. During that year certain members of the New Haven (Conn.) Bird Club did a small amount of banding, but, realizing how unavailing were the efforts of so few,

[2] Address communications to Howard H. Cleaves, secretary-treasurer, Public Museum, New Brighton, N. Y.

decided to carry the cause before the Congress of the American Ornithologists' Union at Cambridge, Mass., in November. There it met with favor and the demand by members of the union for bands became so pronounced that 5,000 were issued prior to the close of the nesting period of 1909. Of this number approximately 1,000 were actually placed on birds, and there resulted from these about 30 . return records by the end of the year. With interest aroused, the time seemed ripe to give the movement a more concrete form than it had hitherto assumed, the result being that some 30 members of the American Ornithologists' Union assembled in New York on the evening of December 8, 1909, and organized the American Bird Banding Association.

Dr. Leon J. Cole, who had been so successfully pushing the work, was chosen president, and together with four able colleagues made up the executive committee. In the spring of 1910, however, Dr. Cole was permanently called to Madison, Wis., and partly as a result of his absence, and also on account of the pressing business affairs of all members of the committee and their widely separated places of residence, the activities of the association were destined to meet with a serious setback. Practically nothing was accomplished during 1910 nor in 1911, but in the fall of the latter year the Linnæan Society of New York offered to foster the work, much to the relief of those previously encumbered with it. A committee (consisting at first of three and subsequently of five) was appointed and a campaign to raise funds in preparation for the nesting season of 1912 was inaugurated and carried forward with considerable success.

At the outset a change in the type of bands seemed advisable and after inquiring among as many as six different European bird banding organizations the style used by Country Life, London, was adopted. Seven thousand five hundred of these bands, of eight different sizes and bearing the inscription " Notify Am. Museum, N. Y.," instead of " Notify The Auk, N. Y.," were ordered. For the purpose of keeping an exact record of every band issued a special ledger was designed and a filing cabinet for record cards and correspondence was purchased. As the spring of 1912 approached post cards were sent out requesting that applications for bands be submitted. So vigorous was the response resulting from these cards and from notices in The Auk, Bird-Lore, Country Life in America, and elsewhere, that 4,173 bands were distributed among 44 persons residing in various parts of the country, and representing such widely separated territories as Nova Scotia, Montana, and Florida. All told, 800 of the bands issued this year (1912) have been actually placed on birds, and some of these have already yielded return records possessing a high degree of interest. The total number of

species banded during the past season is 73, of which the following is a summary:

Species.	Number banded in 1912.	Species.	Number banded in 1912.
Black Guillemot	2	Meadowlark	6
Great black-backed gull	41	Western meadowlark	5
Herring gull	72·	Orchard oriole	1
Least tern	7	Brewer's blackbird	18
Leach's petrel	21	Purple grackle	1
White ibis	28	House finch	1
Glossy ibis	10	Chestnut-collared longspur	1
Bittern	1	Western Vesper sparrow	1
American egret	145	House sparrow	1
Snowy egret	30	Savannah sparrow	20
Louisiana heron	21	White-throated sparrow	1
Little blue heron	17	Chipping sparrow	6
Green heron	2	Field sparrow	4
Black-crowned night heron	10	Song sparrow	15
Spotted sandpiper	19	Slate-colored junco	9
Killdeer	2	Towhee	2
Piping plover	3	Cardinal	3
Mourning dove	4	Rosebreasted grosbeak	1
Marsh hawk	4	Indigo bunting	3
Barn owl	6	Dickcissel	2
Short-eared owl	S	Scarlet tanager	2
Screech owl	2	Purple martin	3
Yellow-billed cuckoo	3	Barn swallow	49
Yellow-bellied sapsucker	1	Red-eyed vireo	3
Red-headed woodpecker	2	Black and white warbler	1
Flicker	25	Yellow warbler	8
Chimney swift	5	Myrtle warbler	1
Arkansas kingbird	10	Black-throated green warbler	1
Great crested flycatcher	5	Louisiana water-thrush	3
Phœbe	19	Catbird	7
Olive-sided flycatcher	2	Brown thrasher	9
Blue jay	9	Chickadee	5
Western crow	2	Wood thrush	4
Bobolink	1	Robin	22
Cowbird	2	Western robin	12
Red-winged blackbird	4	Bluebird	16
Thick-billed redwing	S		

The activity of certain of the banders in the field has been remarkable and their observations often noteworthy. For instance, Mr. Oscar E. Baynard, in charge of Bird Island in Orange Lake, Fla., writes than in placing some 250 bands on white and glossy ibises, egrets, and Louisiana black-crowned night and green herons it was necessary for him to wade about up to his knees in soft mud and guano while the temperature averaged 94° in the shade. Mr. Baynard says further:

I note a white ibis that I banded last year is nesting here this year, although I can not determine the number. Have noted two long whites nesting here this year that were here last year—one adult with deformed leg and a youngster with a deformed foot. This last year's youngster has a nest of its own this year and the old one has built in the same bush she used last year. Next year I will probably be able to note a lot of banded birds returning here to nest.

Mr. A. A. Saunders, of the Forest Service of Montana, is practically the only person doing any banding work in the West, but he

is a host in himself and loses no opportunity to put his bands to good use while ranging over his territory.   In a letter dated June 25, 1912, Mr. Saunders says:

I was recently told of an incident of a marked bird returning to the place where it was born, and got as many of the facts as possible, as I believe they will be of interest to the association. The incident was told me by Mr. E. A. Woods, a forest ranger on the Lewis and Clark National Forest, and while this information comes second hand, I believe it is correct. A lady living near Mountain View, Alberta, just north of the United States boundary, found the nest of a Canada goose and hatched out the eggs under a hen. The young geese lived in the barnyard that summer, and one was marked by fastening a bell around its neck. In the fall, when a flock of migrating geese flew over, the geese left the barnyard, and joined this flock. Two years later, in the spring, the goose wearing the bell returned and stopped in the barnyard for a few days.

Mr. Ernest Harold Baynes, of Meriden, N. H., is one of the most energetic and faithful banders at present engaged in the work, notwithstanding his many other activities. He tells of a flock of 125 white-winged crossbills that fed near his home last winter. The birds were so tame that Mr. Baynes had but to stoop and pick them up when he wished to place bands on their legs. Members of the Meriden Bird Club have put up many nesting boxes for chickadees, bluebirds, etc., and numbers of these small birds have been banded. Indeed, it goes without saying that any bird that falls into the hands of Mr. Baynes wears a ring on its leg when released.

Mr. Harrison F. Lewis, of Yarmouth, Nova Scotia, is another who has accomplished much in the matter of banding the smaller birds. Mr. Lewis told me that when the school children living in the country near him heard of his banding work they all set out to find birds' nests and report them to him. Thus a double end was accomplished— Mr. Lewis was enabled to band dozens of birds without spending much of his own valuable time in looking for nests, and, best of all, the children of the countryside suddenly took a rousing interest in bird life, although perhaps unwittingly. What these children were really keen about was to watch the placing of the tiny aluminum bands on the birds' legs, but to locate the young birds the nests had to be found and in order to find the nests it was necessary to follow the movements and watch the habits of the old birds. It is often difficult to induce children simply to observe things if they think you are trying to make them acquire some knowledge by doing so, but here was a new idea, a material end to be accomplished—something to do. There is no reason why the work of banding birds should not work a similar miracle among adults—it adds a vigorous interest to bird study; arouses latent interest; or even preserves interest when it tends to wane.

These few cases of the activities of field agents are cited as examples of what hundreds of ornithologists should be doing throughout the continent of North America. Bird banding is not the work of a

limited circle but the duty of many, and it is only by extensive banding that results of value can be obtained. Realizing these facts, it has been thought best to welcome the cooperation of all competent bird lovers, regardless of the matter of contributions or annual dues. Anyone deemed properly qualified by the committee may apply for bands and will receive them. On the other hand it is hoped that there are enough people who sufficiently appreciate the value of the work to sustain the necessary financial burden.

A year ago many persons declined to support the work of bird banding on the grounds that not sufficient results had been obtained to establish its practicability. The following return records of banded birds, received within the past 12 months, should rob this objection of its foundation:

On June 7, 1911, an adult chimney swift fluttered down a chimney into the study of Mr. Ernest Harold Baynes in Meriden, N. H., and was promptly banded and released. The band was of the old style and bore the number 6326. At 8 o'clock p. m. on June 15, 1912, two chimney swifts flew from the chimney into the same room of Mr. Baynes' house where the bird had been caught a year and eight days before. And lo! when these birds were taken in hand and examined one of them proved to be 6326. Remarkable as it may seem, this diminutive creature, less than 6 inches in length, had traveled hundreds of miles to Central America or elsewhere in the Tropics where he spent the winter and then made the long return journey at the approach of summer and found again the chimney of his choice in a village of far-off New Hampshire. And throughout his journeyings the little aluminum ring had traveled with him and had produced not the least effect on the bird's leg.

Two French Canadians were gunning along a small river near the hamlet of Whitebread in southwestern Ontario, Canada, on August 5, 1912. Blackbirds, their intended booty, were not numerous and the men were about to return to camp when one suddenly touched the other on the arm and said " You can not hit him!" In answer to this challenge the second gunner wheeled quickly about and took a difficult chance shot at a fast disappearing common tern. There were many terns flying up and down the stream, hovering in the air and plunging for minnows, and it seems strange that the one shot should have borne a band on his leg. The finding of that band resulted in the following letter:

DEAR FRIENDS: As I have never seen you's before, but I am writing a few lines to tell you about a ring or piece of tin I found on a sea gull or sea bird. There is thousands of them here, but I will not try it again. In examining the bird I found on the left leg " Notify the Auk or Ark 4590 New York." So I am doing so to let you know how far this bird traveled. Well, I will close. Please write back and let me know if you got this scribbling.

From

LEO SALOIS, *Box 14, Whitebread, Ont.*

AUGUST 5. 1912.

On referring to No. 4590 among the original banding records it was found that the bird in question had been marked when about 2 weeks old at St. Clair Flats Canal, Mich., on August 13, 1909, by Mr. S. A. Courtis. By corresponding with Mr. Salois it was learned that the terns were apparently not nesting at Whitebread, Ontario, and it is not unlikely that the birds seen there had bred at St. Clair Flats and were indulging in a little roving after the nesting season. However this may be, the fact remains that the dead tern had worn the aluminum anklet for three years minus eight days; had likely made three round trips to the Gulf of Mexico or some other place in the Tropics to spend the winter each year since 1909; and was shot but a comparatively short distance from the spot where he was hatched.

A farmer by the name of August Schilling, of Evansville, Ill., was walking across his fields on April 1, 1912, when he frightened a butcher bird from a fence post, where it had been feeding on what proved to be a bluebird. On picking up the victim and scrutinizing it Mr. Schilling was astonished to discover that the bird wore a ring on its right leg, and that the ring bore an inscription. He wrote a letter to The Auk, New York, giving the number of the band, and asked for information, saying:

Please let me know when the band was put on. There are lots of people would like to know.

This particular bluebird was one of a brood banded by Dr. R. M. Strong, of the University of Chicago, at West Allis, Wis., on July 5, 1909. The band had been carried for two years and nine months, and had apparently caused no inconvenience. It is probable that this bluebird had made two complete migrations to the south, and was about to complete the last lap of a third when he was so unfortunate as to cross the path of *Lanius borealis*.

The letters sent in by persons who have come into possession of banded birds are often intensely interesting, containing information regarding the conditions under which the bird was secured that makes a story of unique character when one goes to the filing cabinet, picks out the banding record, and puts the two halves of the tale together. The following is a good example: The owner of a rice plantation on the Lower Cambahee River, Colleton County, S. C., sent in word that on November 2, 1912, his " bird minder " (a man stationed with a gun in the " rice yard " for the purpose of keeping birds away from the grain) had shot a number of red-winged blackbirds and was preparing them for a potpie when he came upon one wearing a small metal band on its leg. What could be more fraught with interest? The man had, of course, given the number of the band, and we at once picked out the card bearing the record of banding, and supplied the other end of the story. We found that the bird

was banded as a fledgling by Mr. Harry S. Hathaway at Quonochou-
taug, Charlestown, R. I., on June 8, 1912. On being notified of the
" return " Mr. Hathaway wrote:

> I well remember this young red wing. I was wading through a cat-tail
> swamp, looking for redwings' nests, when I spied him clinging to a cat-tail
> about 2 feet from the water. I made a grab and had him in my hand and a
> band on in a jiffy. A toss in the air, and he awkwardly flew some 20 feet, and
> succeeded in grasping an upright cat-tail, and clung there while I went on.

Who would have supposed that the young redwing, reared in a
Rhode Island cat-tail swamp in June, would end his career in a pot-
pie in South Carolina five months later?

Almost every record that has come in is characterized by some dis-
tinguishing feature and would furnish reading matter as interesting
as the several returns cited above. Lack of space, however, prevents
the publication of these embellishments, although the reader may
gather much from the banding and return records in their condensed
form at the end of this paper. The percentage of returns, contrary
to the predictions of some, has indeed been encouraging; and the
point that should be emphasized in connection with these is that they
have not in a single instance been due to the handicapping of the
birds by the bands. This is proved, firstly, by the fact that the
bands have been carried by the birds for such long periods; secondly,
by reason of the very conditions attending the taking of each bird;
and thirdly, by the fact that the presence of the band on the bird's
leg was not in a single case detected until the bird was taken in the
hand and examined, and therefore could not possibly have prompted
anyone to kill the bird for the purpose of recovering the band and
satisfying his own curiosity. This sort of thing, by the way, is and
should be strongly denounced and discouraged. It is rather the
interest in watching for banded birds and even photographing them
that should be encouraged.

It would not be wise to spring at conclusions with regard to the
significance and meaning of the return records that have thus far
been secured. The fact that Mr. Baynes's chimney swift returned to
its old stand after an absence of nearly a year in the Tropics is sig-
nificant in itself; but before stating that, barring accident, chimney
swifts invariably return year after year to the same chimney it
would be advisable, not to say necessary, to obtain a dozen or even
a hundred similar records as corroborative evidence.

Beyond a doubt the greatest progress in the work of banding birds
in America has been made during the year just past, but the pace
established in that time must be not only maintained, but greatly
increased. Our interest and enthusiasm must not decline for a mo-
ment; the work and aims of the American Bird Banding Association
must receive the most zealous support that American ornithologists
are capable of imparting.

Return records.

(a) The returns in this division are from the old lot of bands issued by Dr. Cole in 1909.

7287. HERRING GULL. *Larus argentatus.*

Banded at Falls Pond, Hamilton County, N. Y., by Francis Harper. June 27, 1910. Downy young.

Recovered at Barnegat Inlet, N. J., by William H. Lewis. September 11, 1911. Found alive, but apparently sick, on the shore.

4590. COMMON TERN. *Sterna hirundo.*

Banded at Saint Clair Flats Canal, Mich., by S. A. Courtis. August 13, 1909. About two weeks old. "On bare sandy island left from dredging of new canals. Birds from one to four weeks of age found there."— S. A. C.

Recovered at Whitebread, Ontario, Canada by Leo Salois. August 5, 1912. Shot. Birds did not seem to be breeding here and probably wandered over from Saint Clair Flats after the breeding season.

6625. SPOTTED SANDPIPER. *Actitis macularia.*

Banded at House Is. (Four Bros. Islds.), Lake Champlain, N. Y., by Francis Harper. July 7, 1910. Downy young "caught on July 8 and July 9, examined and found to be in good condition."—F. H.

Recovered at Squantum, Mass., by Hayden Crocker. September 6, 1910. Shot among a flock of smaller sandpipers "on a mudbank in a salt marsh. Did not notice band on leg until I was dressing bird."—H. C.

5557. NORTHERN FLICKER. *Colaptes auratus luteus.*

Banded at Logan Park Cemetery, Sioux City, Ia., by Prof. T. C. Stephens. June 11, 1910. Male nestling, one of a brood of seven.

Recovered at Bayard, Kans., by I. Decker. November 20, 1910. Captured in a barn; injured in capturing and afterwards killed. Band was not noticed until the bird was dead.

6326. CHIMNEY SWIFT. *Chætura pelagica.*

Banded at Meriden, Sullivan Co., N. H., by Ernest Harold Baynes. June 7, 1911. Adult: "This bird and another came down the chimney and into my study at 8 p. m. It was almost dark when we liberated them."— E. H. B.

Recovered at Meriden, Sullivan Co., N. H., by Ernest Harold Baynes. June 15, 1912. Caught in a room. "The leg to which the band was attached appeared normal in every way."— E. H. B.

955. RED-WINGED BLACKBIRD. *Agelaius phœniceus phœniceus.*

Banded at Berwyn, Chester, Co., Pa., by Leonard S. Pearson. June 6, 1909. Fledgling: "had just left nest."— L. S. P.

Recovered at Lansdowne, Delaware Co., Pa., by H. L. Henry. September 1, 1909. Shot.

5838. FIELD SPARROW. *Spizella pusilla pusilla.*

Banded at Sioux City, Ia., by Prof. T. C. Stephens.
June 11, 1910.
Fledgling.

Recovered at Sioux City, Ia., by A. Kirkegaard.
May 23, 1911.
No information as to how it was obtained.

3429. WESTERN HOUSE WREN. *Troglodytes aëdon parkmani.*

Banded at Milwaukee, Ore., by William L. Finley.
July 31, 1909.
Nestling.

Recovered at Woodburn, Ore., by son of J. G. Martzoff.
June 26, 1910.
Found in watering tank. Woodburn is about 30 miles south of Milwaukee.

251. ROBIN. *Planesticus migratorius migratorius.*

Banded at Kingston, R. I. (Orchard of Agricultural College) by Leon J. Cole and Wm. F. Kirkpatrick.
August 4, 1908.
Half-fledged bird from " nest about 10 ft. up in an apple tree."—L. J. C.

Recovered at Kingston, R. I. (Poultry plant of Agricultural College) by Wm. F. Kirkpatrick.
April 9, 1909.
" Presence of band was unknown until bird was in the hand. Specimen taken to aid in pathological work at station. Band had caused no abrasion or other injury to foot."—L. J. C.

1212. ROBIN. *Planesticus migratorius migratorius.*

Banded at Bangor, Me., by Ora Willis Knight.
July 8, 1910.
" Young bird found on ground barely able to fly. Banded and released."—O. W. K.

Recovered at Nashville, Tenn., by J. G. Jenkins.
February 21, 1911.
" Captured."

2376. ROBIN. *Planesticus migratorius migratorius.*

Banded at Westbrook, Cumberland Co., Me., by Arthur H. Norton.
July 21, 1909.
Nestling.

Recovered at Westbrook, Cumberland Co., Me., by Arthur H. Norton.
July 27, 1909.
Killed by a cat at night; bird left the nest July 27.

1271. ROBIN. *Planesticus migratorius migratorius.*

Banded at Portland, Me., by Ora Willis Knight.
July 29, 1912.
Fledgling, just out of the nest.

Recovered at Portland, Me., by Chas. E. Foss.
August 3, 1912.
Killed by a cat on a lawn " two and a half blocks north of spot where bird was banded."—O. W. K.

2816. BLUEBIRD. *Sialia sialis sialis.*

Banded at West Allis, Wis., by Dr. R. M. Strong.
July 5, 1909.
Nestling; "one of a brood of several."—R. M. S.

Recovered at Evansville, Randolph Co., Ill., by August Schilling.
April 1, 1912.
Killed by a Northern Shrike, *Lanius borealis.*

6302. BLUEBIRD. *Sialia sialis sialis.*

Banded at Meriden, Sullivan Co., N. H., by Ernest Harold Baynes.
June 3, 1911.
About two weeks old; "one of a family of five in an unpainted wooden box, on the corner of an old shed."—E. H. B.

Recovered at Berlin, Md., by son of a millhand in the employ of Charles W. Tingle.
January 20, 1912.
Shot together with others of a flock of Bluebirds.

(b) The following have resulted from the new lot of bands issued in the spring of 1912.

5804. GREAT BLACK-BACKED GULL. *Larus marinus.*

Banded at Lake George, Yarmouth Co., N. S., by Howard H. Cleaves.
July 23, 1912.
Fledgling.

Recovered at Mavillette, Digby Co., N. S., by Frank S. Doucet.
December 18, 1912.
Caught alive. "Bird seemed half tame, due probably to some ailment. Band moved easily up and down the tarsus."—F. D.

5830. GREAT BLACK-BACKED GULL. *Larus marinus.*

Banded at Lake George, Yarmouth Co., N. S., by Howard H. Cleaves.
July 26, 1912.
Fledgling; "a few of these birds (about three dozen were banded) were seen later from my blind. They paid no attention to the bands."—H. H. C.

Recovered at Cape Negro Is., Shelburne Co., N. S., by Ashley Smith.
October 4, 1912.
Shot by Mr. Smith when gunning.

5832. GREAT BLACK-BACKED GULL. *Larus marinus.*

Banded at Lake George, Yarmouth Co., N. S., by Howard H. Cleaves.
July 27, 1912.
Fledgling.

Recovered at Prout's Neck, Cumberland Co., Me., by G. Clifford Libby.
December 6, 1912.
Found dead on the beach.

7115. PIPING PLOVER. *Ægialitis meloda.*

Banded at Katama, Martha's Vineyard, Mass., by Howard H. Cleaves.
July 3, 1912.
Three days old, one of a family of three.

Recovered at south shore of Martha's Vineyard, Mass.
August 2, 1912.
Shot by a boy.

PLATE 1.
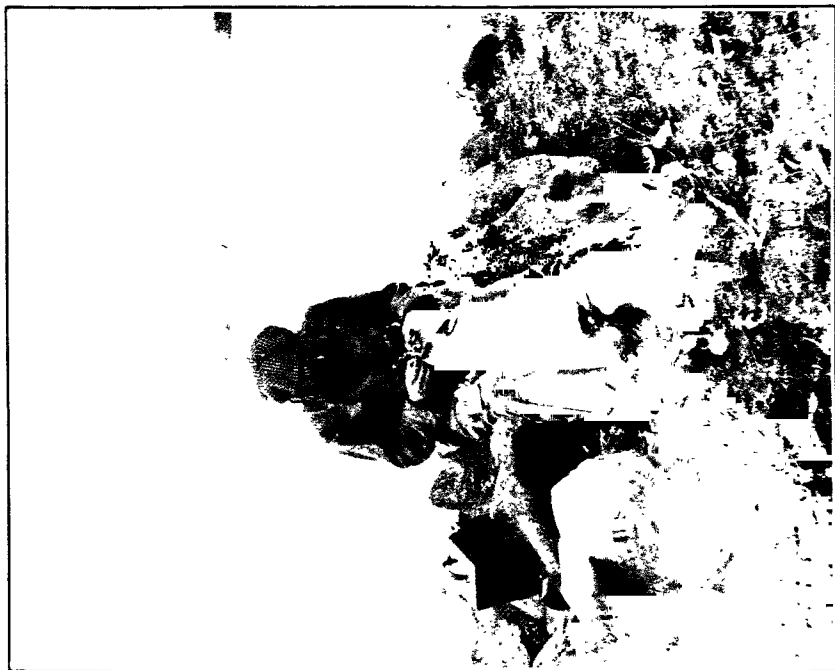
1. BANDING BLACK-BACKED GULLS IN THE LAKE GEORGE (NOVA SCOTIA) COLONY.
2. YOUNG BLACK-BACKED GULL WITH BAND ON FOOT.

PLATE 2.
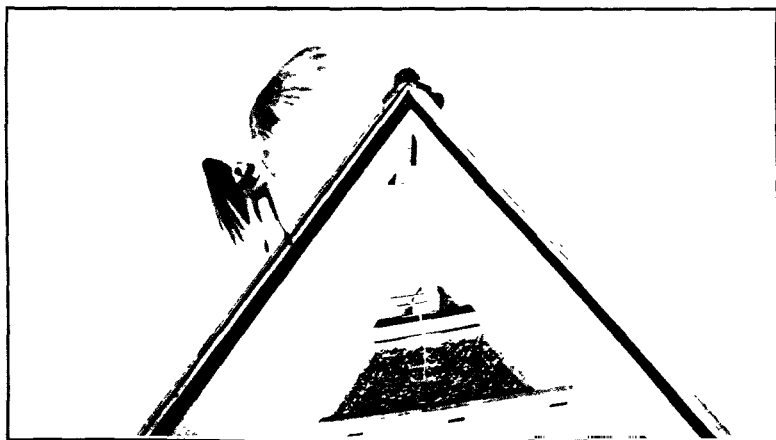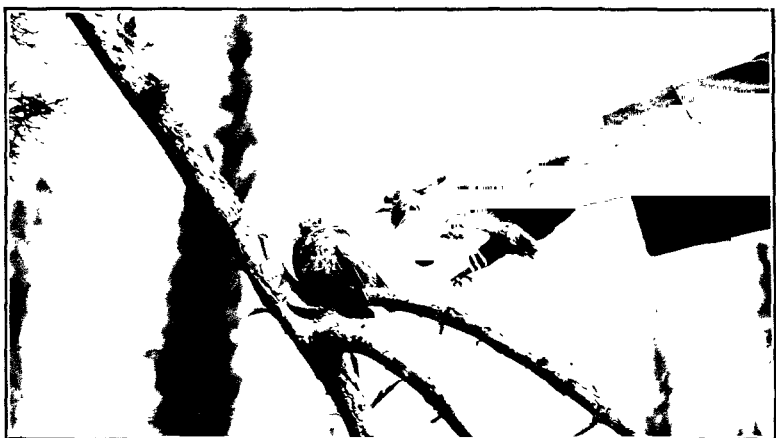
1. YOUNG MOURNING DOVES, BANDED AT STATEN ISLAND, N. Y.
2. CHIMNEY SWIFT, BANDED AT MERIDEN, N. H.
3. BARN OWL, BANDED AT STATEN ISLAND, N. Y.

12. RED-WINGED BLACKBIRD. *Agelaius phœniceus phœniceus.*

Banded at Quonochoutaug, Charlestown, R. I., by Harry S. Hathaway.
June 8, 1912.
Fledgling; "caught with the hands and when released alighted on a cat-tail."—H. S. H.

Recovered at Green Pond, Colleton Co., S. C., by Thomas Grant.
November 2, 1912.
Shot by a "bird minder." ("A small blackbird known as the red-winged blackbird, in the fall very destructive to rice.")—D. J. Chaplin, owner of plantation.

6261. PHŒBE. *Sayornis phœbe.*

Banded at Meriden, Sullivan Co., N. H., by Ernest Harold Baynes.
June 6, 1912.
Adult, nest in old house in Corbin Park.

Recovered at Meriden, N. H., by Mrs. Ernest Harold Baynes.
July 14, 1912.
Found dead beneath nest; "could assign no cause for death. As far as I could see the presence of the band had had nothing to do with the case. The bird had laid one egg of the second set."—E. H. B.

Explanation of plates.

PLATE 1.

FIG. 1. Banding young black-backed gulls (*Larus marinus*) in the Lake George, Nova Scotia, Colony, July 25, 1912. Photograph by G. K. Noble.
FIG. 2. Banded young black-backed gull, Lake George, Nova Scotia, 1912.

PLATE 2.

FIG. 1. Two young mourning doves (*Zenaidura macroura carolinensis*) banded at Staten Island, N. Y. City, May, 1912. Game birds or others shot for food are most likely to produce return records.
FIG. 2. Chimney swift (*Chœtura pelagica*) banded at Meriden, N. H., in June, 1911, and returned, after wintering in the tropics, to his old chimney in New Hampshire, June, 1912. Photograph by Ernest Harold Baynes.
FIG. 3. Old barn owl (*Aluco pratincola*) and her five young banded at Staten Island, N. Y. City, June, 1912. Only one pair of these birds is known to nest each year on the island, and banding is likely to cast light on the problem of dispersal of the young.
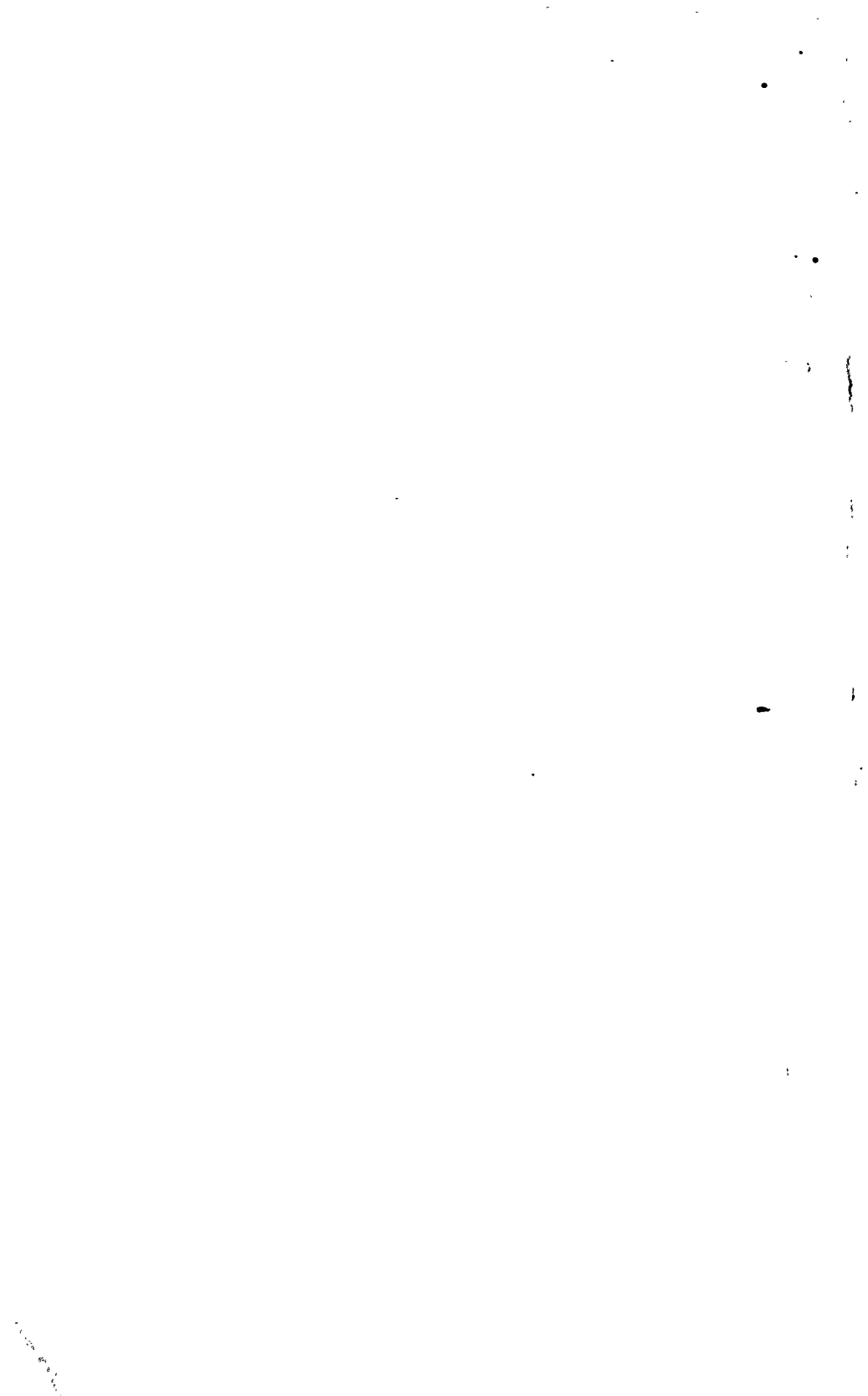
THE WHALE FISHERIES OF THE WORLD.[1]

By CHARLES RABOT.

[With 3 plates.]

After a long period of decadence the whale fishery has again experienced a considerable revival. In all parts of the world, at the present time, this interesting industry is being actively carried on, and, according to the Norwegian Fisheries Gazette (*Norsk Fiskeritidende*), not less than 20,000 cetaceans are captured every year, so that the disappearance of these great marine mammals in the near future seems certain.

Never very abundant, the right whales, that is the Arctic right whale, or Greenland whale, and the North Atlantic right whale, or Nordcaper, of which the oil served to light the way of our ancestors of the seventeenth and eighteenth centuries, and of which the whalebone was used to shape the figures of our great-great-grandmothers, have become very rare. In our time the Greenland whale is not regularly hunted except in Davis and Lancaster Straits, in Hudson Bay, and on the northwest coast of North America about Point Barrow. Even in those places it is no longer abundant. In 1910 the vessels from Dundee, which alone visited Davis Strait, took only 17 whales, in 1908 and in 1909 about 15, so that in spite of the high prices paid for the whalebone of this species, sometimes as much as $8,000 a ton, the Scotch whalers were frequently obliged to abandon their enterprise.

On the northwest coast of America the Greenland whales appear more numerous. No statistics of the fishery in this region are available, but the data now at hand indicate that the results in 1909 and 1910 were excellent. In 1910, one vessel harpooned 15 of these huge cetaceans in this locality, and a second reported a cargo of whalebone worth $130,000.

The second species of right whale, the North Atlantic right whale or Biscay whale, is at present scarcely more abundant than the Greenland whale. It was, indeed, believed to be extinct, when one was harpooned near Iceland in 1888, and another the following year, five

in 1890, and seven in 1891. Since then some of these whales have been captured from time to time in the North Atlantic. Furthermore, in later years a certain number of right whales of other species, regarding which no statistics have been published, have been taken in the South Seas.

In contrast with the foregoing, finbacks and humpbacks abound. in all seas, such as the blue whale (*Balœnoptera sibbaldii*), the rorqual (*B. musculus L.*), the Pollack whale (*B. borealis*), the common humpback (*Megaptera nodosa*), and many other less well-known species. These cetaceans are at present relentlessly pursued for commercial purposes. The finbacks present this special difference from the right whales, that they have only short whalebone, and consequently less value. By way of compensation, all the other parts furnish remunerative products. The fat of these mammals yields a good quantity of oil, and the residue of the distillation, together with the flesh, serve for the manufacture of a "guano" when the carcasses are reduced to a powder. Finally, the meat is used for food.

FIG. 1.—MAP OF WHALING STATIONS IN AFRICA.

This finback whale fishery began 47 years ago on the northern coast of Scandanavia, and was due to the ingenuity of the celebrated Norwegian sailor, Svend Foyn. To the inventive spirit of this man are due the destructive machines now in use, which are boats of 100 to 150 tons, very speedy and carrying at the bow a gun that throws a harpoon to which a line is attached; in a word, the same system as that of the *canon-porte-amarres*. With this armament Svend Foyn in 1867 captured his first whale, and in the first year took 30. Less than 15 years afterwards the fortunate inventor found himself possessed of more than $2,000,000. Encouraged by this example, companies were organized to exploit this source of profit, to such an extent that in 1887 there were no less than 35 whaling vessels on the coast of Finmark—that is, on the portion of the Norwegian coast between Hammerfest and the Russian frontier. In good years they captured from 1,200 to 1,300 finbacks. Soon, however, the inhabitants of this region made a violent protest against this new industry, which they asserted threatened to ruin them.

PLATE 1.
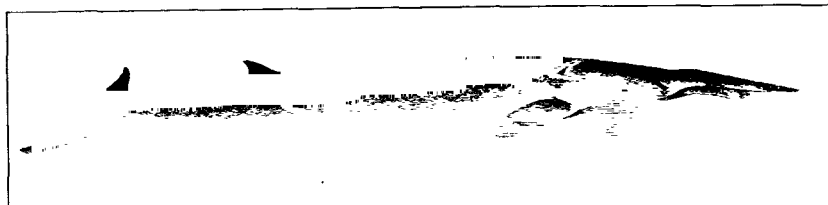
COMMON FINBACK WHALE.
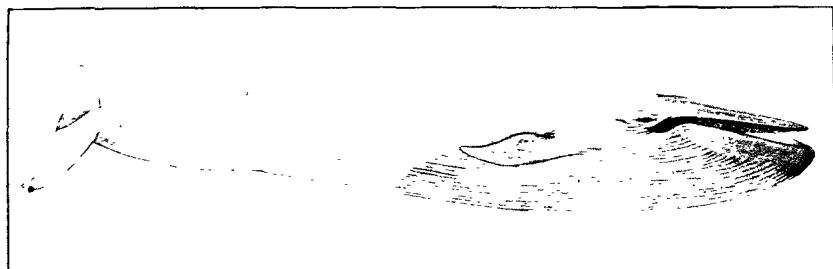
SULPHUR-BOTTOM WHALE.

NORTH AMERICAN HUMPBACK WHALE.

Every spring great schools of codfish arrive on this coast in pursuit
of the capelan, on which they feed and which approach the land to
escape them. The cod are very fond of these little fish, and the
fishermen assert that the whales also pursue them, and that the
capelan, in order to escape, seek refuge in the shallow waters along
the coast, thereby bringing the codfish near to land. The whales,
becoming less numerous on account of the destructive fishery which
is carried on for them, the capelan find themselves less actively pur-
sued and remain offshore, along with the codfish, if we may credit
the statement of the natives. In consequence, the cod fishery, which
is the principal resource of Finmark, becomes more difficult and more
precarious. The natives do not hesitate to impute the bad results
of many seasons during the last decade to the whalers. Researches
conducted by the most competent zoologists, however, indicate that
no relation of cause and effect exists between the destruction of the
whales and the greater or less abundance of codfish on the coast of
Finmark. The fisherman did not on that account abandon their
fixed idea, and as a result of their violent agitation the Norwegian
Parliament prohibited whale fishing on the northern coast for a
period of 10 years, beginning with 1904.[1]

While this discussion was going on the Norwegian whalers estab-
lished themselves little by little on all the coasts frequented by the
finbacks in Iceland, the Faroe Islands, Newfoundland, Japan, South
Africa, and, finally, in the Antarctic. Everywhere this industry
is carried on by the fishermen of Sandefjord and Tönsberg, the
home of Svend Foyn. Companies are formed in America or in
Africa by means of local capital, but it is to the men of Sandefjord
or Tönsberg that they confide the management of the enterprise,
and it is from among them that they recruit their personnel. Finally,
when, as in Japan, native fisheries are established, it is still to the
Norwegian shipyards that they turn for the construction and equip-
ment of the whaling vessels. For this reason every year the Nor-
wegian Fisheries Journal publishes interesting statistics of the whale
fishery, by the aid of which we are able to present a summary of the
results of this interesting industry in 1911 throughout the world.

In Europe there are but four places in which the fishery is carried
on: The coast of the British Isles, the Faroe Islands, Iceland, and
Spitzbergen. Seven companies, employing 16 steamers,[2] operate on
the coast of Great Britain, four at the Shetlands, one at the Heb-
rides, and two on the west coast of Ireland. In 1911 they caught
632 whales[3] (355 at the Shetlands, 146 at the Hebrides, and 131 off
Ireland), while in the preceding years the number taken rose to

[1] This prohibition, ending this year, was prolonged.
[2] Seventeen in 1913.
[3] In 1913 the catch was 548.

735 or 745. During the last year (1911), the product of the fisheries did not exceed 3,355 metric tons of oil, consequently the amount per whale was not more than 209.5 tons, while in 1910 it was 221 tons and in 1909, 297.5 tons. This circumstance is not due to a decrease in the number of whales, but to bad weather and to the inexperience of the gunners employed on several steamers. It is interesting to note that in the waters of Great Britain 17 Atlantic right whales were captured in 1910, 20 in 1907, and 6 in 1906. It was a capture well worth while, as the whalebone of this species is worth from $5,000 to $10,000 a ton.[1]

At the Faroe Islands there are six companies with 15 steamers. In 1911 their booty was only 344 finbacks and two sperm whales. In 1907 the number was double. This capture of sperm whales was a fortunate circumstance. In one of them two pieces of ambergris were found weighing 17.5 kilograms and valued at $10,500. In 1910 one Atlantic right whale was also captured in this region.[2]

In Iceland there are also six companies, with about 25 steamers.[3] According to the statistics, which are incomplete, only 350 were taken in 1911, while in the preceding year double that number were obtained, and 843 in 1907. This ground, therefore, seems exhausted or at least less rich than formerly. Several of the companies were dissolved and others abandoned this region to reestablish themselves in the South Seas, where the results are far more remunerative.

Immediately after the prohibition of whaling on the northern coast of Norway, several companies were established at Spitzbergen. In 1907 there were six companies with 13 steamers, and a seventh at Bear Island with two boats. That year, on account of the large amount of ice in these two localities, only 333 finbacks were taken. Since that date most of the companies have abandoned this archipelago and only two remain in Isfjord, one at Green Harbor and the other at Safe Harbor. In 1910 they caught 165 whales and in 1911 144 more, one of which was a Greenland whale. This very rare species was obtained off the northwest point of Spitzbergen,[4] in 80° north latitude. In 1913 there was a catch of 845 whales in the North Atlantic and Arctic Oceans from the English Channel to Spitzbergen.

In Asia the principal center of the whale fishery is in Japanese waters where it has been practiced from a very early day. Twenty or twenty-five years ago, in consequence of the introduction of the new apparatus, this industry developed rapidly. It was at first in the hands of the Norwegians, but little by little, owing to the bounties given by the Imperial Government, the Japanese superseded

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[1] The price of whalebone has since lowered.
[2] In 1913 there were only two companies at Faroe Islands.
[3] Three companies only in 1913. The companies are moving toward the eastern regions.
[4] There is no more whale fishery (1913) at Spitzbergen.

PLATE 2.

CHASING WHALES NEAR THE SHETLAND ISLANDS.

From photograph by Dr. Charcot.

PLATE 3

Smithsonian Report, 1915. —Risbot

FIG. 1.—NORWEGIAN WHALING STATION AT GREEN HARBOR, SPITZBERGEN.

From photograph by Dr. Howl.

FIG. 3.—A WHALE STEAMER.
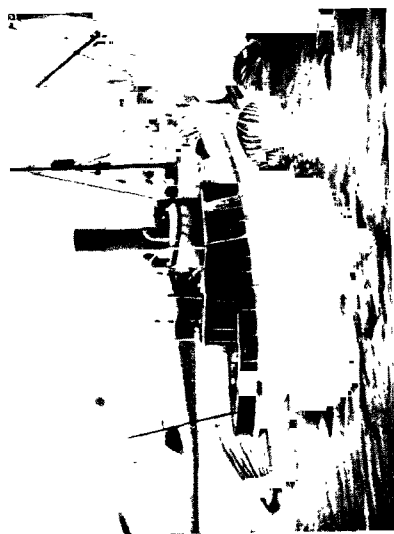
FIG. 2.—RETURN TO PORT AFTER THE CHASE.
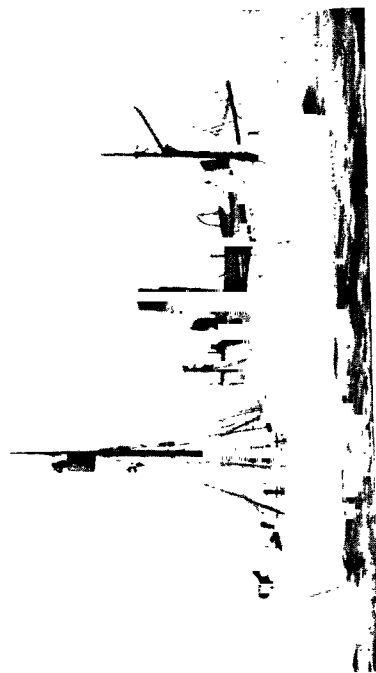
them, though taking care to retain the more capable gunners. There are at present in Japan seven native companies with 28 vessels. In 1909 the most important of them, which alone possessed 20 steamers, captured 605 whales. The preceding year, the Japanese harpooned 784 whales. In 1911 one Russian whaler operated in the vicinity of Saghalin and Bering Strait, but the venture was scarcely profitable, as but six whales were taken.

In North America whales are pursued on the west coast of Greenland, at Newfoundland and in the mouth of the St. Lawrence, and on the coast of British Columbia. Last year (1911) finbacks were hunted for the first time on the west coast of Greenland, but the results were not very satisfactory, as only 24 whales were taken. At Newfoundland 274 whales were harpooned in 1910, and in the vicinity of the island and in the mouth of the St. Lawrence the results of the fishery were also mediocre. On the coast of Alaska, on the contrary, the number of whales taken in 1910 amounted to 1,300. In 1911, up to July 1, the catch of three steamers only was 247. In 1912 two companies with five steamers were operating. The catch was 644 whales.

In South America, one station was established in 1911 and four in 1912 on the coast of Brazil, another at the Falkland Islands, and in 1913 two more stations were established there, one company taking 87 whales; while on the coast of Chile three companies operated in 1911 and ten in 1912.

Since 1908 South Africa has become one of the most productive centers of the whale fisheries. South of 12° 30′ south latitude not less than 12 stations have been established. Five of these, with 10 steamers, are located in Angola, at Bahia de Lobito, at Elephant Bay, at Mossamedes, at Port Alexandria, and at Tiger Bay. On the coast of Cape Colony are two stations with four vessels, one at Saldana Bay, and the other at Mosser Bay; also in Natal, near Durban, three companies with nine steamers, and finally in Mozambique Channel, two stations, with four boats at Inhambane and at Angoche.

In 1911, these 12 stations produced not less than 17,000 metric tons of oil. According to the Norwegian Fisheries Journal four companies alone captured 1,472, and it would not be excessive to estimate the number taken during the last season around South Africa at 2,000; there were 23 stations around that coast in 1912.

The destruction of whales in the Antarctic has been much greater. In 1911 not less than 10,000 finbacks and humpbacks were killed in the Antarctic Seas around South America. It was following the exploration carried on between 1901 and 1903 by Prof. Otto Nordenskjöld in the land situated south of Cape Horn that the whalers took their way to the South Polar Seas, a proof, it may be said in

passing, that these scientific enterprises often lead to profitable economic results. In the course of this expedition Larsen, the captain of the Swedish exploring vessel, an experienced whaler, observed the presence of numerous humpbacks about South Georgia, and in December, 1904, he established himself on the island to hunt these whales. The enterprise having proved a complete success, others followed his example. In 1911 six companies with 18 boats operated on this island and all were extremely successful. As the Norwegian Fisheries Journal points out, there is in this region a truly extraordinary abundance of whales, and the number of cetaceans, chiefly humpbacks, taken at South Georgia during the last season is estimated at the enormous number of 7,000. Of 970 whales taken by one company 937 were humpbacks.

The sulphurbottoms and common finbacks are both very abundant, but, because they are more combative and more difficult to kill, they are less disturbed. When the supply of humpbacks diminishes their turn will come. Every year some right whales are captured in this locality. During the southern summer of 1908–1909, 69 of them were taken.

The 7,000 whales above mentioned produced 34,000 metric tons of oil, or double the production for the whole world only four years previously. This enormous quantity would fill a basin in which a whaler—that is to say, a steamer of from 100 to 120 tons—could maneuver.

On South Georgia, which was previously uninhabited, actual industrial villages have been established. A church has been erected, and there are three slips for cutting up the whales, two guano factories, reservoirs for the oil, and houses for the staff. This Antarctic island has a floating population of many hundreds of sailors and workmen. A doctor resides there during the whaling season and, since 1908, the British Government has established a post office in this polar land.

Farther to the south, in the region situated west of Cape Horn, and explored by Dr. Charcot with so much profit to science, a new whaling ground not less rich has been discovered. In 1907 the whalers who operated in the Strait of Magellan conceived the idea of pushing forward to the South Shetlands. They soon took up the enterprise and in a few weeks made 374 captures, including 73 right whales. Such success attracted much attention, and the following year four companies sent their steamers to Deception Island, in the archipelago. They captured not less than 2,000 whales, according to Dr. Charcot. In 1910 they obtained only 1,461 whales, chiefly humpbacks. In the meantime the whaling had become very difficult. The whales had, so to speak, completely deserted the waters of Deception Island, where they had previously been so abundant,

and had withdrawn far toward the southwest into the Strait of Gerlache. The whalers sought to recover them and had no cause to regret their labors. The strait literally boiled with whales, so much so that in a single day a boat would capture six or eight of them.

In 1911 this industry received a new extension. Last year the number of boats in this region increased to 22, belonging to eight different companies. In this season as in the preceding one the Strait of Gerlache was the principal center of operations and Port Lochroy the anchorage discovered by Charcot. In Wiencke Island was the general rendezvous of the whalers in this region. The hydrographic surveys executed by the French Antarctic expedition thus served the interests of commerce.
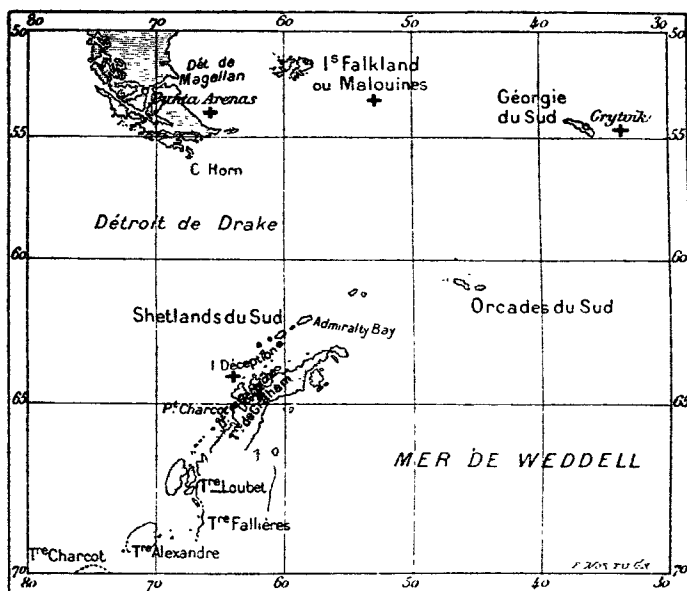
FIG. 2.—MAP OF WHALING STATIONS IN THE ANTARCTIC OCEAN.

According to many accounts, the strait was full of whales, to use the picturesque expression of the Norwegian Fisheries Journal, and every day they were killed without mercy, so that for quite a long period one oil works was being replenished constantly by new supplies and manufactured as much as 68,000 kilos of oil in a day. The result of the season's work was represented by 16.061 tons of oil furnished by 3,000 whales, of which 17 were right whales.

In 1913 nine companies with 32 steamers were established in the South Shetlands. They caught more than 3,000 whales.

To conclude the enumeration of the whaling ground we will mention Kerguelen Island. In 1908–9 a Norwegian company established in this archipelago captured 232 whales, among them one right

whale. The following season was much less favorable, only 82 finbacks having been taken, and in 1910-11 the total captures did not exceed 87. Furthermore, during these two last years some of the steamers belonging to the South African companies went to Kerguelen Island. In 1910 one of these harpooned 41 whales.

Approximately, then, in 1911 there were 3,000 whales taken in the seas of Europe and North America, about 2,000 in South Africa, and 10,000 in the Antarctic, making a total of 15,000 whales, but this estimate is much too small, since neither Japan nor South America is included in the calculation. For the last season, 1911, the production of oil is estimated by the Norwegian Fisheries Journal at 102,000 metric tons, or twice the production of 1910. Nevertheless, prices did not decline. Indeed, for a certain time they were very high, varying at Christiania from 56 centimes to 61 centimes per kilogram.
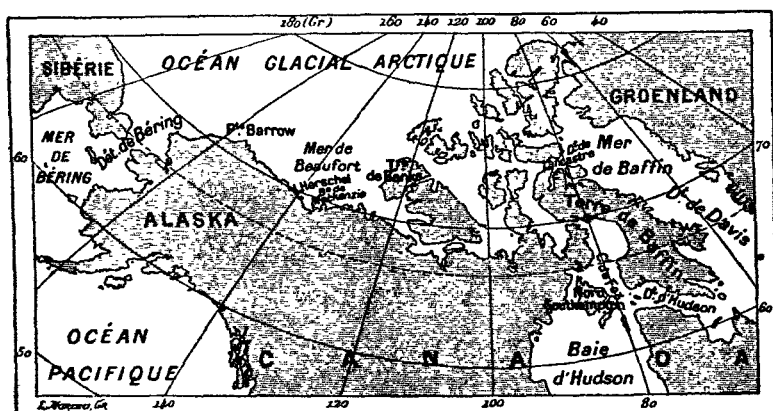
FIG. 3.—MAP OF WHALING STATIONS IN THE ARCTIC OCEAN.

The price of guano was also very firm, and the whalebone of the finbacks was in much demand. That of the sulphurbottom and the common finback varied from 1,893 francs, 75 centimes, to 1,767 francs, 50 centimes, per ton, while the whalebone of the humpbacks did not bring more than 883 francs, 75 centimes. On the contrary, the whalebone furnished by the right whale brought only from 30,000 to 35,350 francs per ton, a very low price for this article, which is usually so much in demand.

The stability of prices gave a new impulse to the whaling industry. At the end of 1911, 15 important new Norwegian companies were formed and, in addition, a much larger number of smaller companies. Four of them intended to operate on the coasts of South Africa, which would bring the number of those established in this region up to 20; two intended to locate in Alaska and eight in the seas of New Zealand and Australia. Finally, one company proposed to

establish itself at the South Orkneys and the South Sandwich Islands. At South Georgia the British Government authorized the establishment of only one new company, organized in England. Many years ago Great Britain took possession, not only of this island, but also of the South Orkneys, the Sandwich Islands, the South Shetlands, and all that portion of the Antarctic continent situated south of America. We believe that the Government of King George V proposed to continue these annexations in the south polar regions, for which we may congratulate ourselves. Owing to the police system and the taxes established by the British Government, whaling in the Antarctic Seas is regulated to a certain degree, and the influx of too great a number of whalers is arrested.

In conclusion, we may add that this industry does not require very large capital. The funds of the large Norwegian companies scarcely exceed one-and-a-half million francs, and when a rich whaling ground happens to be found the profits become enormous. In two years a company with a capital of 910,000 francs installed at South Georgia twice distributed a dividend of 130 per cent, besides adding a portion of the profit to various reserve funds and increasing the company's resources 60 per cent.

THE MOST ANCIENT SKELETAL REMAINS OF MAN.

By Dr. A. Hrdlička,

Curator, Division of Physical Anthropology, U. S. National Museum.

[With 41 plates and 12 figures.]

INTRODUCTION.

The early history of the human race, though merged in the darkness of ages, is step by step being traced and reconstructed; and apparently the time is drawing near when science will be able to announce, in the main at least, the definite solution of the profound and involved problem of man's origin, when, in other words, it will be in a position to show, however imperfectly, when, where, and how man ascended from the lower orders.

Actual research into the antiquity of mankind began considerably less than a century ago, and the more intensive investigations in this field cover hardly a generation. Such investigations have been fraught with many difficulties and are growing in complexity. They demand patient watchfulness, diligent and long-extended exploration, and considerable expense. The most careful attention must in every case be given to geological and paleontological evidence. And, after all, the net results of a prolonged quest may be no more than a few stone chips and implements, or perhaps a tooth, or a few badly crushed bones, belonging to human antiquity. But, as there are many hands at work, invaluable materials are accumulating. Besides this every now and then the search is more richly rewarded, or some important specimen is discovered accidentally; and every new, well-authenticated addition to the remains of early man or his predecessors, more particularly if it is a part of the skeleton, means a fresh, highly valuable document which throws supplementary light on the natural history of the human being.

The explorations of recent years have been particularly fruitful. They were of wide extent geographically and have brought to science stores of primitive archeological remains, so that whole classes of ancient industries in stone could be determined; and they resulted in the recovery of example after example of well-authenticated

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ancient skeletal remains representing men coeval with long-extinct animals, and with them dating far back into the Quaternary or Ice Epoch.

The aggregate of the precious skeletal material here referred to is still far from being satisfactory from the standpoint of completeness, but it is already sufficient to afford solid groundwork for important scientific deductions as to man's development; and happily exploration is going on with ever-increasing interest as well as precision. Hundreds of well-trained students are now watching and searching for new accessions with which to corroborate previous observations, to fill in the gaps, and to bring about a fuller understanding of the physical progress of man in the course of the ages.

Europe, particularly in its more western and southern portions, has thus far proved the richest in ancient human remains. Africa, Asia, and those parts of Oceanica which were formerly connected with the Asiatic continent have as yet been but little explored. The island of Java, however, which is within the last-named region, has furnished an intensely interesting specimen bearing on man's evolution and antiquity. As to America, the researches have thus far yielded nothing that could possibly be accepted as representing man of geological antiquity.[1] For the present, therefore, an account of the very ancient remains of man, with the exception of the Java specimen, must be limited to early European forms.

Such an account, in condensed form, is here presented. With the view of preparing this summary the writer, during part of the spring and summer of 1912 and under the auspices of the Smithsonian Institution, undertook a personal examination of all the more important skeletal remains relating to early man now preserved in the museums of Europe. The cultural remains were given only passing attention, partly on account of their great numbers and partly because they pertain to a collateral branch of science, prehistoric archeology, which is rapidly making them known to the world.[2] The sites of the more noteworthy discoveries were visited, however, whenever circumstances permitted.

In this communication there will be described only the very oldest of the human skeletal remains so far recovered. Besides these, the European museums possess numerous human crania and bones belonging to more recent time and therefore not of such decided general interest as the older forms, and also some whose reported age

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[1] The question of Early Man in North and South America is dealt with in Bulletins 33 and 52 (published respectively in 1907 and 1912) of the Bureau of American Ethnology, Smithsonian Institution; these publications also contain the bibliography of the subject.

[2] See "Recent discoveries bearing on the antiquity of man in Europe," by G. G. Mac-Curdy, Smithsonian Report for 1909, Washington, 1910; the Comptes Rendus du Congrès International d'Anthropologie et d'Archéologie Préhistoriques, especially the sessions at Monaco and Geneva; also L'Anthropologie," "Man," and other anthropological periodicals.

is not generally regarded as well established. These two classes of specimens can not well be considered in this paper for it would thereby become unduly extended and possibly also involve controversy.

The questions of the antiquity and origin of man are natural subjects of the greatest interest both to the scientist and to the layman, for they touch the very foundations of human beliefs, ethics, and organic progress in the future. Their detailed solution, also, is still far from us. But it may now be safely postulated that man did not appear on our planet as an entirely new and distinct being unconnected with the rest of terrestrial organic life; for he is anatomically as well as physiologically but a highly specialized mammal that still carries numerous though now more or less useless vestiges or reminders of various lower stages through which he passed. Neither is there any good reason to regard him as the result of some freak of evolution, for his progress in the organic scale seems thoroughly logical and, judging from what has been already learned on the subject, his ascent, though probably not uniformly accelerated, was on the whole slow. We shall seemingly come nearest the truth if we look upon him as on the ultimate result of gradual modification in the upward continuity or differentiation of a highly important group of organic forms. He may be regarded as the topmost and dominating bough on an ancient mammalian tree whose roots intertwine, somewhere in the earlier Tertiary, with those of other vertebrate forms. From this tree various branches have doubtless diverged at different levels and become related species, some of these still persisting, while others have been long extinct. The stem began, so far as discernible, with lemurlike forms, from which in the course of time sprang, though scarcely in the order in which they now appear to us, the more simple and then the more highly organized primates. Among the latter then arose, it would appear, slowly or more likely rather suddenly, one or perhaps several forms characterized by more than the average physical instability; and the descendants of one or more of these strains, under the influence, in all probability, of changing environment, more especially food and climate, with perhaps other agencies, began more or less gradually to develop reduced teeth, larger brain, more erect posture, with increased facility of intercommunication; and this differentiation apparently progressed until some strain of these changing beings reached that hazy dividing line below which was still the realm of the apes but above which commenced that of the true *predecessors* of man.

The more immediate human precursors may be conceived of as forms which showed various individual advances anatomically, physiologically, and mentally toward man, as well as many morphological and other reminders of and reversions to the ape; but they

were unable to revert wholly to the latter. On the whole, they kept, probably irregularly, progressing toward man, and when eventually a part of them varied so far in the direction of the human being that a complete return even to their own former kind became impossible, then, it may be conceived, the earliest representatives of man were established. These earliest men doubtless from the beginning lacked in uniformity; some strains of them, in all likelihood, lacked also in vitality or in sufficient adaptability to changing conditions and have disappeared; but others kept on modifying in the upward direction until in the course of long ages they reached the various somewhat unequally advanced types of man of the present day.

The above deductions concerning man's origin seem to be justified from the study of the material now at the disposal of the anthropologist. The whole process of man's rise, viewed comprehensively, appears as a most remarkable, multiple, progressive, sustained, possibly more or less irregular, and not yet finished differentiation, the exact and enduring causes of which are not well understood. The various actual species of primates lower than man may in a sense be viewed as by-products of his own evolution, partly perhaps as his distant cousins, descendants from some of the old primate stocks, or as the retarded and aberrant relatives, unable or not called upon by their environment to keep up with his progress, and slowly modifying more or less sui generis. The old mono- and polygenistic theories dissolve, of course, equally before these closer assumptions.

The final stages of the progression toward the human form, according to such light on the subject as we now have, began toward the close of the Tertiary period. By the end of the Tertiary it seems probable that there already existed some of the transitional forms, the predecessors of the human being, approaching present man in size of skull and brain, in the character of the teeth, in stature, in the form of the pelvis, and in other particulars. It is even possible that before the close of this period man's precursors began the use of articulate language, and thus passed the somewhat more definite functional boundary separating these forerunners from man. But the bulk of the life history of the human being proper belongs to the Quaternary period, the period of repeated advances and retrogressions of glacial climate over the North Temperate Zone. The oldest known human remains have been found in deposits and with the bones of extinct animals of glacial or interglacial times. As we go backward into that period we find that the human forms and in general also the products of human activities become more primitive. On the other hand, after the last glacial recession, some eight thousand or more years ago, man was already physically much like he is to-day.

The time that has elapsed since the new anthropoid, or rather superanthropoid beings progressing toward man developed the physical characteristics that may be regarded as distinctively human, and acquired the faculty of speech, can not be computed in years, but the length of that period must have been many times greater than the duration of our recent or Holocene epoch, the relatively brief phase since the recession of the last ice invasion.[1]

THE OLDEST WELL-AUTHENTICATED SKELETAL REMAINS OF MAN NOW EXISTING.

THE "PITHECANTHROPUS."

(Pithecanthropus erectus Dubois.)

In 1891–92 Dr. E. Dubois, then a surgeon in the Dutch Army, while engaged in paleontological excavations along the left bank of the Bengavan River, near Trinil, in the central part of the Island of Java, discovered several skeletal parts of a primate evidently higher in scale and nearer to man than any before known.

The remains were thoroughly petrified and comprised, in all, the vault of a skull, two molar teeth, and a femur.

The bones were not found simultaneously nor in the same place. They lay some distances apart, though at the same horizon and embedded in the same stratum of volcanic matrix. This stratum was rich in fossil remains of various organic forms and, in the locality where the excavations were carried on, was about 1 meter below the dry-season water level, or 12 to 15 meters below the plain in which the river had cut its bed.

In September, 1891, the excavations in the volcanic matrix yielded unexpectedly, among other fossils, a remarkable tooth, a molar, which was determined as having belonged to a large unknown primate. A month later the unique and most interesting skull cap was discovered, only 1 meter distant from the place where lay the tooth. It now became certain that traces had come to light of a hitherto unknown primate of large size, standing in many respects nearer to man than any of the actual anthropoid apes. It was seemingly an intermediate form between the apes and man, and was characterized by the name of "*pithecanthropus.*"

Then came the rainy season and work had to be suspended. Exploration was recommenced, however, as early as possible in 1892, and in August of that year the femur was found about 15 meters (50 feet) from the locality where the other specimens had been em-

[1] For the duration and subdivision of the Glacial Epoch the following works may be consulted: T. E. Chamberlin and R. D. Salisbury's Geology, 1906; Osborn, H. F., The age of mammals in Europe, Asia, and North America; H. Obermaier, Der Mensch der Vorzeit, 8°, Berlin, 1912; and R. R. Schmidt, E. Koken and A. Schliz, Die Diluviale Vorzeit Deutschlands, 4°, Stuttgart, 1912. These works give further bibliography.

bedded. Finally, in October of the same year, the second molar was secured, at a distance of not more than 3 meters (13 feet) from the original position of the skull cap, and in the direction of the resting place of the femur.

The accompanying illustrations (pl.[1] and text fig. 1) show the locality of the discovery and the approximate positions of the specimens.
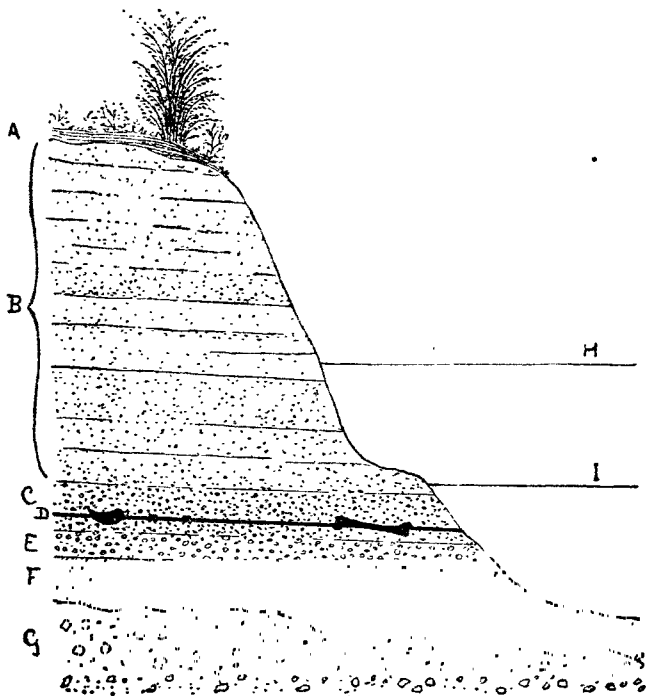
FIG. 1.—SECTION OF THE OSSIFEROUS STRATA AT THE LOCALITY WHERE THE PITHECANTHROPUS BONES WERE DISCOVERED. A, AREA OF GROWING PLANTS; B, SOFT SANDSTONE; C, LAPILLI STRATUM; D, LEVEL AT WHICH THE SKELETAL REMAINS WERE FOUND; E, CONGLOMERATE; F, ARGILLACEOUS LAYER; G, MARINE BRECCIA; H, WET-SEASON LEVEL OF THE RIVER; I, DRY-SEASON LEVEL OF THE RIVER. (After Dubois, Smithsonian Report for 1898.)[2]

All four specimens were considerably mineralized, being of chocolate-brown color, very heavy, and "harder than marble." Numerous bones of mammals found in the same bed belonged to species now extinct or, so far as known, not now living in Java, and showed fossilization similar to that of the bones of the Pithecanthropus. The contours of the teeth and the femur were sharp, indicating that

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[1] After Mme. L. Selenka and M. Blankenhorn: Die Pithecanthropus-Schichten auf Java, 4°, Leipzig, 1911.

[2] From the Smithsonian Report for 1898, p. 446, article Pithecanthropus erectus, by Eugène Dubois (translated from the Anatomischer Anzeiger, vol. 12, pp. 1–22); original in Trans. Royal Dublin Soc., vol. 6, 1896, pp. 1–18.

PLATE 1.

THE LOCALITY OF THE PITHECANTHROPUS FIND, ON THE BENGAVAN RIVER, NEAR TRINIL, JAVA (AFTER MME. SELENKA AND M. BLANKENHORN).

The two white squares show where the femur (on left) and the skullcap (on right and more behind) were discovered

it has not been washed or rolled about to any great extent; but the skull cap showed the effects of erosion, probably caused by acidulous water seeping through the deposits.

All indications and a detailed study of the specimens led Dubois to the conclusions that: (1) The four skeletal pieces in question were contemporaneous; (2) they were of the age of the stratum in which found; (3) they belonged to one skeleton; and (4) they represent a transitional form of beings between the anthropoid apes and man, belonging to the direct line in the genealogy of the latter.

The first published announcement of the discovery by Dubois appeared in 1894; [1] to-day the subject possesses already a relatively large literature of its own. [2] A special expedition of two years' duration has also since worked on the site of the discovery, [3] and the remains are regarded universally as of the greatest scientific value; but the final word concerning their exact age and true biological position has not yet been pronounced.

It should be stated at once that there is no room for doubt as to the place of discovery of the several bones and their geological or paleontological relations. The several pieces were found in situ, in the progress of scientific exploration, by a careful and competent observer. But the precise age of the stratum in which they lay, and their exact biological position among related forms, are not yet absolutely delimited. While Dubois and other scientific men regard the Pithecanthropus remains as all belonging to the same skeleton, as dating chronologically from the latest part of the Tertiary or the earliest phase of the Quaternary period, and as representing a true intermediary form between the anthropoid apes and man, others have expressed doubts as to whether the four bones belong to the

[1] Pithecanthropus erectus. Eine menschenähnliche Übergangsform aus Java. Von Eug. Dubois, Militärarzt der Niederländischen Armee. Mitt zwei Tafeln und drei in den Text gedruckten Figuren., 4°, Batavia, 1894.

[2] Few of the more important English contributions to the subject are:

Marsh, O. C. On the Pithecanthropus erectus Dubois, from Java. (Amer. Journ. Sci., Feb. 1895.) On the Pithecanthropus erectus, from the Tertiary of Java. (Ibid., 4th ser., vol. 1, 1896, pp. 475–482.)

Turner, William. On M. Dubois's description of remains recently found in Java, named by him Pithecanthropus erectus, with remarks on the so-called transitional forms between Apes and Man. (Journ. Anat. and Physiol., vol. 29, 1895, pp. 424–445.)

Dubois, E. On Pithecanthropus erectus: a transitional form between man and the apes. (Journ. Anthrop. Instit. Great Britain and Ireland, Feb. 1896, pp. 240–255; Trans. Royal Dublin Soc., ser. 2, vol. 6, Dublin, 1898, pp. 1–18; Smithsonian Report for 1898 (Washington, 1899), pp. 445–459.)

Manouvrier, L. On Pithecanthropus erectus. Transl. by G. G. MacCurdy. (Amer. Journ. Sci., 4th ser., vol. 4, Sept. 1897, pp. 213–234.)

Hepburn, David. The Trinil femur (Pithecanthropus erectus) contrasted with the femora of various savage and civilized races. (Rep. 66th meeting Brit. Assoc. Adv. Sci., 1897, pp. 926–927.)

For literature in other languages see especially G. Schwalbe, Studien ü. Pithecanthropus erectus Dubois. (Zeitschr. f. Morphologie und Anthropologie, Bd. 1, Stuttgart, 1899, pp. 1–240, bibliogr. 234–240.)

[3] Under Mme. Selenka; see "Die Pithecanthropus-Schichten auf Java," by Mme. Lenore Selenka and M. Blankenhorn, 4°, Leipzig, 1911.

same form; or they consider the age of the remains, though no doubt early Quaternary, to be less than that estimated by Dubois; and finally some incline to regard the remains as those of early man rather than an intermediary being, while still others consider that they represent merely a superior extinct form of ape.[1]

BRIEF DESCRIPTION OF THE SPECIMENS.

(Plates 2, 3, text fig. 2.)

On account of peculiar circumstances an attempt to describe first hand the important pieces under consideration meets with serious difficulties. It would surely seem proper and desirable that specimens of such value to science should be freely accessible to well-qualified investigators and that accurate casts be made available to scientific institutions, particularly after 20 years have elapsed since the discovery of the originals. Regrettably, however, all that has thus far been furnished to the scientific world is a cast of the skull cap, the commercial replicas of which yield measurements different from those reported taken of the original, and several not thoroughly satisfactory illustrations; no reproductions can be had of the femur and the teeth, and not only the study but even a view of the originals, which are still in the care of their discoverer, are denied to scientific men. Under these anomalous conditions it is only possible to follow Dr. Dubois's old information.[2]

The skull cap (pl. 2) measures in greatest length 18.5 (on cast 18.1) cm., in greatest (parietal) breadth 13 (on cast 13.3) cm., and at the minimum of the frontal constriction 8.7 cm.[3] It is dolichocephalic, its outline as seen from above is oblongly ovoid, narrowing considerably forward, and it is very low. It presents excessively prominent though not massive supraorbital arch and a very sloping front. The frontal bone, in addition, shows externally and along its middle a well-defined ridge, running from a short distance above the glabella toward bregma, and a marked low protuberance just forward of the bregma. The sagittal region is relatively flat and smooth, and the occiput presents a dull transverse crest, connecting as in apes, though in much less pronounced manner, with the supramastoid crest on each side.

[1] For numerous of the earlier phases of these controversies see Dubois's paper in the Transactions of the Royal Dublin Society; also that in the Smithsonian Report for 1898, p. 449 et seq.

[2] The extended and meritorious work on the skull by Schwalbe (op. cit.) was made on a cast, which evidently was in all respects identical with the one in the U. S. National Museum, but the measurements on which do not exactly agree with those given by Dubois on the original. These differences, however unfortunate, do not, of course, in any way detract from the importance of the original.

[3] For comparison it may be stated that similar measurements on an ordinary white male American dolichocephalic cranium give approximately 19.1, 14.3, and 10 centimeters; on female, 18.3, 13.7, and 9.6 centimeters.

1a
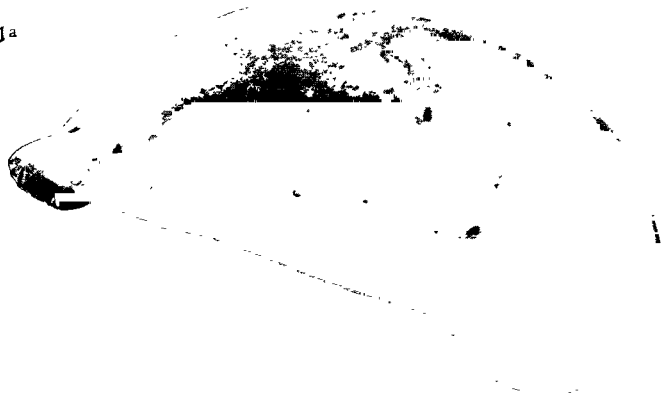
2a

1a. PITHECANTHROPUS ERECTUS, SKULLCAP, FROM LEFT SIDE (ONE-HALF NATURAL SIZE).
2a. ANTHROPOPITHECUS TROGLODYTES, ADULT FEMALE SKULL, FROM LEFT SIDE (TWO-THIRDS NATURAL SIZE).

(After Dubois, Smithsonian Report for 1898.)

PLATE 3.

Smithsonian Report. 1893.—Hrdlička.

1.) PITHECANTHROPUS ERECTUS SKULLCAP FROM ABOVE (ONE-HALF NATURAL SIZE).
2.) ANTHROPOPITHECUS TROGLODYTES, ADULT FEMALE SKULL, FROM ABOVE (TWO-THIRDS NATURAL SIZE).

After Dubois. Smithsonian Report for 1898.

Without going into a detailed discussion of these characteristics, it will suffice to say that in most respects the specimen differs more or less from the ordinary human skull of to-day as well as from those of early man, so far as known, and approaches correspondingly the crania of the anthropoid apes.

The temporal ridges, marking on the parieties of the vault the upper limit of the temporal muscles and fascia, are well defined but run rather distant (about 4 cm. on each side) from the median line, as in female anthropoids and in man. This suggests that the cranium
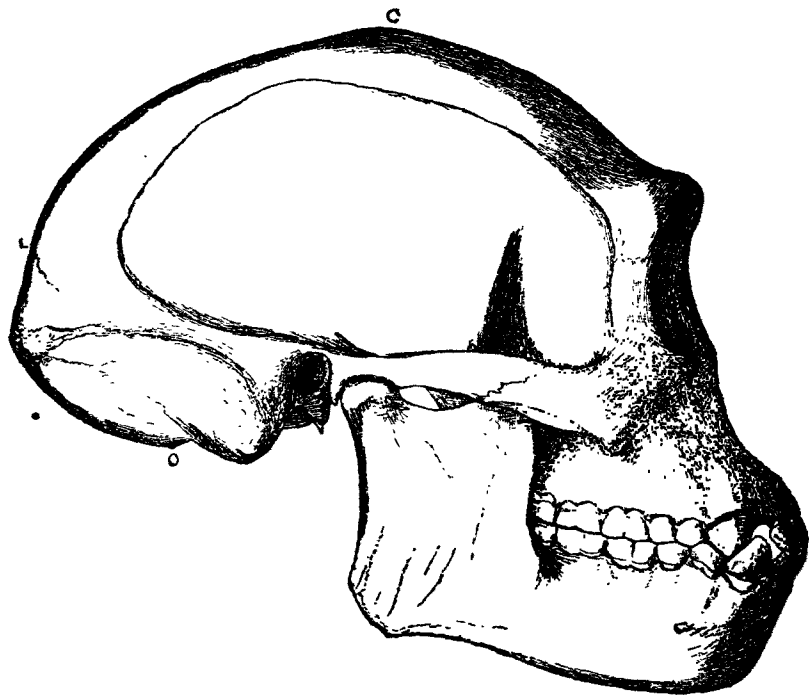
FIG. 2.—ATTEMPT AT A RESTORATION OF THE SKULL OF THE PITHECANTHROPUS ERECTUS HALF THE NATURAL SIZE. (After Dubois, Smithsonian Report for 1898.)

may be feminine. The whole remnant, in fact, presents rather subdued forms, such as would more readily be expected in a female than in a male being at that stage of evolution.

The walls of the skull are of only moderate thickness. Its internal capacity was originally believed by Dubois to have been quite large, namely about 1,000 c. c., but eventually he reduced this estimate to 900 c. c. or a little over. The capacity of an average cranium of a white American would amount in the male to about 1,500, in the female to about 1,350 c. c., while in the largest living anthropoid apes it only rarely attains or exceeds 600 c. c.

The impression which a comprehensive study of the whole skull cap carries to the observer is, that it represents a hitherto unknown primate form, which, whatever it may eventually be identified with and whether or not man's direct ancestor, stands morphologically between man and the known anthropoid apes, fills an important space in the hitherto existing large void between the two. and constitutes a precious document for the natural history of man.

Dubois's theoretical restoration of the whole cranium of the Pithecanthropus, which in all probability comes fairly near to the reality, is shown in the foregoing illustration (fig. 2).

The two teeth attributed to the Pithecanthropus are the second left and the third right upper molars. The latter is shown, in reduction, on plate 4. According to Dubois, they both present the same type, which, particularly in the development of the cusps, is markedly ape-like; but Tomes[1] pronounces them "not exactly like any known teeth, either human or simian." Judging from the models of these teeth which the writer saw at Haarlem, they are decidedly unlike any human molars, but approach those of the higher anthropoids. Both have bulky but rather low crowns, and stout, not too long, strongly diverging roots. In size they exceed considerably the same teeth in man, as will be seen from the comparisons given herewith; their relative dimensions (that is, the ratio of breadth to length) are, however, rather nearer the human form than that in most of the large apes.

Comparison of the corresponding molars of modern white man and the Pithecanthropus.

	Second left upper molar.		Third right upper molar.	
	Greatest length (sagittal diameter).	Greatest breadth (transverse diameter).	Greatest length.	Greatest breadth.
	mm.	mm.	mm.	mm.
Average white man, approximate	9.5	11.0	9.0	10.5
Pithecanthropus	12.0	14.0	11.3	15.3

On the whole, it seems evident that the two teeth represent a higher primate form; in all probability they come from one individual, and their morphological characteristics are such that they may well have belonged to the same species or even the same individual as the before-described skullcap. Their size, as seen from a comparison with the teeth of larger existing anthropoid apes, is not incompatible with the size of the skullcap, and that even if the latter belonged to a female individual.

[1] Dental anatomy, 8°, London, 1904, p. 560.
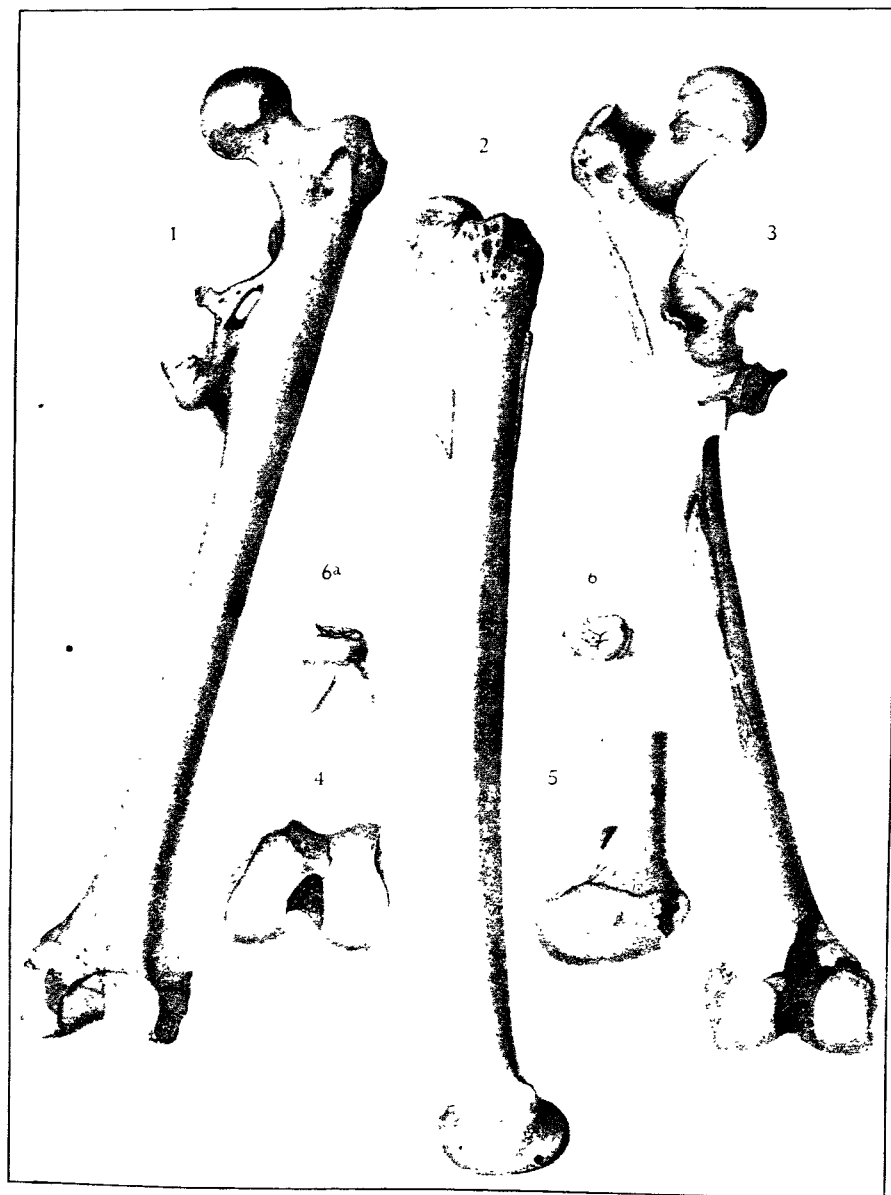
PITHECANTHROPUS ERECTUS.

Left femur 1 from before; 2, from side, 3, from behind 4 from below 5, lower end from median side, 6, right third upper molar, from below; 6a, from behind. (Reduced, after Dubois, from Smithsonian Report for 1898.)

PLATE 5.

THE GRAVEL BED AT PILTDOWN, FROM THE DARKEST STRATUM OF WHICH, RESTING ON THE BEDROCK, THE FOSSIL HUMAN SKULL AND JAW WERE OBTAINED.

(After Charles Dawson.)

The Trinil femur (pl. 4), according to Dubois, Manouvrier, and others, bears a close resemblance to the human thigh bone, both in size and shape; nevertheless judging from the illustration it presents also some important differences. Its length, 45.5 cm., equals that of a human femur from a man 1.70 meters (5 feet, 7 inches) in stature, and of proportionate strength.[1] Notwithstanding these dimensions, however, the relatively large inclination of the bone from the vertical when stood up on its condyles, and the relatively moderate-sized head and lower articular extremity, suggest that, as was the case with the skullcap, the bone may proceed from a female.

The femur plainly belonged to a strong being maintaining erect or near-erect posture and marching mostly or entirely biped, as man.

The principal differences of the bone from a modern human femur consist in its less-marked antero-posterior curve, in a more evenly cylindrical shaft, in the more mesial position of the smaller trochanter, in the intertrochanteric line being less raised and hence more simian in character, and in the popliteal space which, as a rule concave from side to side in present man, is convex in the Trinil specimen.

THE "EOANTHROPUS DAWSONI."

A somewhat problematical as yet but deeply interesting find of ancient human skeletal remains has recently come to light in England. The specimen representing this discovery is an imperfect cranium, with a part of the lower jaw and a canine tooth. It is known as the Sussex or Piltdown skull, or more technically as the *Eoanthropus Dawsoni*, and its preservation is due to Mr. Charles Dawson. It is deposited in the British Museum of Natural History at Kensington and was first reported, with the circumstances of the find, on December 18, 1912, before the London Geological Society.[2]

The history of this specimen, as given by Mr. Dawson, illustrates the usefulness and need, especially in the Old World, of scientific supervision of excavations. Mr. Dawson's statement is as follows:[3]

Several years ago I was walking along a farm road close to Piltdown Common, Fletching (Sussex), when I noticed that the road had been mended with some peculiar brown flints not usual in the district. On inquiry I was astonished to learn that they were dug from a gravel bed on the farm, and shortly

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[1] The circumference of the shaft at middle is 9 cm., or one-fifth of the length of the bone, which proportion is often equaled in present man; the breadth at middle is 2.75 cm. Numerous other measurements of the bone are given in Dubois's "Pithecanthropus erectus," etc., 4°, Batavia, 1894. p. 21, et seq.

[2] Dawson, Charles, A. Smith Woodward, and G. Elliot Smith. On the discovery of a Palaeolithic skull and mandible in a flint-bearing gravel overlying the Wealden (Hastings beds) at Piltdown, Fletching (Sussex). (Quart. Journ. Geol. Soc. for March, 1913, vol. 69, pp. 117–144.) See also Haddon, A. C., Eoanthropus Dawsoni (Science, Jan. 17, 1913, pp. 91–92); and MacCurdy, G. G., Ancestor hunting: The significance of the Piltdown skull (Amer. Anthropologist, vol. 15, 1913, pp. 248–256).

[3] L. c., p. 117 et seq.

afterwards I visited the place, where two laborers were at work digging the gravel for small repairs to the roads. As this excavation was situated about four miles north of the limit where the occurrence of flints overlying the Wealden strata is recorded I was much interested and made a close examination of the bed. I asked the workmen if they had found bones or other fossils there. As they did not appear to have noticed anything of the sort I urged them to preserve anything that they might find. Upon one of my subsequent visits to the pit, one of the men handed to me a small portion of an unusually thick human parietal bone. I immediately made a search, but could find nothing more nor had the men noticed anything else. The bed is full of tabular pieces of ironstone closely resembling this piece of skull in color and thickness; and, although I made many subsequent searches, I could not hear of any further find nor discover anything—in fact, the bed seemed to be quite unfossiliferous.

It was not until some years later, in the autumn of 1911, on a visit to the spot, that I picked up, among the rain-washed spoil heaps of the gravel pit, another and larger piece belonging to the frontal region of the same skull, including a portion of the left superciliary ridge * * *.

I took the bones to Dr. A. Smith Woodward at the British Museum (Natural History) for comparison and determination. He was immediately impressed with the importance of the discovery, and we decided to employ labor, and to make a systematic search among the spoil heaps and gravel as soon as the floods had abated, for the gravel pit is more or less under water during five or six months of the year. We accordingly gave up as much time as we could spare since last spring (1912) and completely turned over and sifted what spoil material remained; we also dug up and sifted such portions of the gravel as had been left undisturbed by the workmen * * *.

At Piltdown the gravel bed occurs beneath a few inches of the surface soil and varies in thickness from 3 to 5 feet * * *.

Portions of the bed are rather finely stratified, and the materials are usually cemented together by iron oxide, so that a pick is often needed to dislodge portions—more especially at one particular horizon near the base. It is in this last mentioned stratum that all the fossil bones and teeth discovered in situ by us have occurred. The stratum is easily distinguished in the appended photograph (pl. 5) by being of the darkest shade and just above the bedrock.

The gravel is situated on a well-defined plateau of large area * * * and lies about 80 feet above the level of the main stream of the Ouse.

Since the deposition of the gravel the river has cut through the plateau, both with its main stream and its principal branch, to this extent.

Considering the amount of material excavated and sifted by us, the specimens discovered were numerically small and localized.

Apparently the whole or greater portion of the human skull had been shattered by the workmen, who had thrown away the pieces unnoticed. Of these we recovered from the spoil heaps as many fragments as possible. In a somewhat deeper depression of the undisturbed gravel I found the right half of a human mandible. So far as I could judge, guiding myself by the position of a tree 3 or 4 yards away, the spot was identical with that upon which the men were at work when the first portion of the cranium was found several years ago. Dr. Woodward also dug up a small portion of the occipital bone of the skull from within a yard of the point where the jaw was discovered and at precisely the same level. The jaw appeared to have been broken at the symphysis and abraded, perhaps when it lay fixed in the gravel and before

its complete deposition. The fragments of cranium show little or no sign of rolling or other abrasion, save an incision at the back of the parietal, probably caused by a workman's pick.

A small fragment of the skull has been weighed and tested by Mr. S. A. Woodhead, M. Sc., F. I. C., public analyst for East Sussex and Hove, and agricultural analyst for East Sussex. He reports that the specific gravity of the bone (powdered) is 2.115 (water at 5° C. as standard). No gelatine or organic matter is present. There is a large proportion of phosphates (originally present in the bone) and a considerable proportion of iron. Silica is absent.

Besides the human remains, we found two small broken pieces of a molar tooth of a rather early Pliocene type of elephant, also a much-rolled cusp of a molar of *Mastodon*, portions of two teeth of *Hippopotamus*. and two molar teeth of a Pleistocene beaver. In the adjacent field to the west, on the surface close to the hedge dividing it from the gravel bed. we found portions of a red deer's antler and the tooth of a Pleistocene horse. These may have been thrown away by the workmen. or may have been turned up by a plough which traversed the upper strata of the continuation of this gravel bed. Among the fragments of bone found in the spoil heaps occurred part of a deer's metatarsal, split longitudinally. This bone bears upon its surface certain small cuts and scratches which appear to have been made by man. All the specimens are highly mineralized with iron oxide. * * *

Among the flints we found several undoubted flint implements, besides numerous Eoliths. * * *

From the above Mr. Dawson believed himself justified in drawing the following conclusions:

It is clear that this stratified gravel at Piltdown is of Pleistocene age, but that it contains in its lowest stratum animal remains derived from some destroyed Pliocene deposit probably situated not far away and consisting of worn and broken fragments. These were mixed with fragments of early Pleistocene mammalia in a better state of preservation, and both forms were associated with the human skull and mandible. which show no more wear and tear than they might have received in situ. Associated with these animal remains are Eoliths, both in a rolled and an unrolled condition; the former are doubtless derived from an older drift, and the latter in their present form are of the age of the existing deposit. In the same bed, in only a very slightly higher stratum, occurred a flint implement. the workmanship of which resembles that of implements found at Chelles. and among the spoils heaps were found others of a similar, though perhaps earlier. stage.

From these facts it appears probable that the skull and mandible can not safely be described as being of earlier date than the first half of the Pleistocene (or Glacial) epoch. The individual probably lived during a warm cycle of that age.

The anthropological report on the specimen by Dr. Woodward brings forth the following main details:

The human remains comprise the greater part of a brain case and one ramus of the mandible, with lower molars 1 and 2. All the bones are normal, with no traces of disease, and they have not been distorted during mineralization.

Of the brain case there are four pieces (reconstructed from nine fragments) sufficiently well preserved to exhibit the shape and natural relations of a larger part of the vault and to justify the recon-

struction of some other features. These bones are particularly note-worthy for their thickness, which reaches 20 mm. at the internal occipital protuberance and 10 mm. along the greater part of the fractured edges of the frontal and parietals. The average thickness of modern European skulls, except in the locality of the various ridges and sutures, varies between 4 and 6 mm.

The greater portion of the brain case may be reconstructed without any hypothetical restoration, the only serious deficiency being the middle portion of the frontal region above and including the larger portion of the supraorbital ridge. Such a reconstruction, with a justifiable amount of modeling, has been skillfully made by Mr. Frank O. Barlow in the Palaeontological Laboratory of the British Museum. * * * It is shown in plate 6.

The reconstructed cranium (pl. 6) is evidently that of an adult, but not old, female. Seen from above, it shows a short ovoid out-line. It is wide posteriorly, measuring 15.0 cm. across its widest part, just behind the zygomatic arch, and tapering moderately for-ward to a slight constriction behind the supraorbital ridge, where its width (the diameter frontal minimum) is 11.2 cm. The total length from the middle of the supraorbital ridge (glabella) to the external occipital protuberance (inion) is uncertain, owing to the hypothetical restoration of the frontals, but it measured probably not far from 19.0 cm. The cephalic index may have been, therefore, somewhere about 78 or 79.

In anterior view the relative narrowness of the frontal region is well shown, and the vault is seen to rise to the vertex at the widest part of the skull. In side view this upward slope is still better seen, and the steeply curved frontal contour is especially noteworthy. The external occipital protuberance (inion) seems to form the hindmost point of the cranium, though the portion of the occipital immediately above it is in an almost vertical plane.

In back view the contour of the skull is very remarkable. It is relatively low and wide, and gently arched above, with the sides flattened in their upper half, and the mastoid region either vertical or slightly inclined inward. * * *

A detailed examination of the several bones of the skull is interesting, as proving the typically human character of nearly all the features that they exhibit. The only noteworthy reminiscences of the ape are met with in the upward extension of the temporal fossæ and in the low and broad shape of the occiptial region. The frontal region, which is complete on the left side and in its upper middle portions, shows a fairly developed forehead, with well-rounded frontal eminence. Judging from the remainder of the supraorbital border, it is clear that there can not have been any prominent or thickened supraorbital ridge, and in consequence of this the missing parts of the frontal region were restored on the plan of an ordinary human skull—

which was, perhaps, not fully justifiable.

The temporal crest is sharply developed over the frontal and parietals.

Immediately behind the middle of the coronal suture the parietal region is distinctly flattened; but as it expands backward, the roof soon rises to a broad rounded vertex. The parietal eminences are conspicuous. The nearest ap-

PLATE 6.

FIRST RESTORATION OF THE SKULL AND MANDIBLE OF EOANTHROPUS DAWSONI.

(After Dawson and Woodward.)

proach of the upper line of the temporal crest to the sagittal suture is 36 mm., a distance frequently equaled in the present man. The parietal suture is completely obliterated, but the lambdoid is open and parts of it show well-developed serration. The squamous suture is well arched, as in the typical modern human skull.

The occipital bone is remarkable both for its relatively great width, and for the large area and flattenings of its smooth upper portion. The external occipital protuberance and the muscular ridges are well marked.

The left temporal bone, which is excellently preserved, is "typically human in every detail," and corresponds closely with the same bone in a comparatively modern human skull. The mastoid is rather small.

The capacity of the brain-case can not, of course, be exactly determined; but measurements both by millet-seed and by water show that it must have been at least 1,070 cc., while a consideration of the missing parts suggests that it may have been a little more. It therefore agrees closely with the capacity of the brain-case of the Gibraltar skull, as determined by Prof. Keith, and equals that of some of the lowest skulls of the existing Australians. It is much below that of the Mousterian skulls from Spy and La Chapelle-aux-Saints.

The intercranial cast shows, according to Elliot Smith, "a considerable resemblance to the well-known palaeolithic brain-casts, and especially to those obtained from the Gibraltar and La Quina remains. * * * Like these it is relatively long, narrow, and especially flat; but it is smaller and presents more primitive features than any known human brain or cranial cast." Marked peculiarities of conformation are shown particularly in the parietal and temporal region. The length of the left cerebral hemisphere was only 16.3 cm., due to the thickness of the bones, while the maximum breadth of the brain (located lower down than usual), was 13.0 cm., the maximum height 10.6 cm.[1] The author concludes that "taking all its features into consideration, we must regard this as being the most primitive and most simian human brain so far recorded; one, moreover, such as might reasonably have been expected to be associated in one and the same individual with the mandible, which so definitely indicates the zoological rank of its original possessor."

As regards the lower jaw and the teeth it will be best to quote again from Dr. Woodward. According to this observer: "While the skull, indeed, is evidently human, only approaching a lower grade in certain characters of the brain in the attachment for the neck, the extent of the temporal muscles and in the probably large size of the

[1] The brain of a white male from Ireland, whose skull possessed very nearly the same external measurements (length 19 cm., breadth 14.9 cm.), gave the writer 17 cm. in length, 13.8 cm. in breadth, and 11.8 cm. in height.

face, the mandible appears to be almost precisely that of an ape, with nothing human except the molar teeth * * *." What there is of the lower jaw shows the same mineralized condition as the skull, and the specimen " corresponds sufficiently well in size to be referred to the same individual without any hesitation." It is fairly well preserved. " It lacks the condyle and a larger part of the symphysis with most of the dental arch, but retains the first two molars, as well as the socket for the third. The ascending ramus is relatively broad. The bone is massive and its outer surface is deeply marked with irregular hollows for the insertion of a powerful masseter muscle. The horizontal ramus measures only about 27 mm. in height behind, but must have been a little higher forward. There is a great width of the temporal insertion, the mylohyoid groove is situated behind rather than in line with the dental foramen, and there is a complete absence of the mylohyoid ridge—all characters of the mandible in apes, not in man. As the horizontal ramus curves round to the symphysis its lower margin exhibits an increasingly wider flattening, which begins beneath the second molar, slopes upward and outward, and ends in front in the strongly retreating chin. The inner edge of this flattening is sharply rounded, and at the symphysis itself the inner face of the jaw is so much depressed in its lower part that the bone here has the form of a nearly horizontal plate or flange, closely similar to that found in all the apes. The genio-hyo-glossal and genio-hyoid muscles, in fact, must have had their origin in a deep pit, as in the apes; while the digastric can only have been inserted on the edge of the bony flange instead of extending far over the lower border as in man. Unfortunately, the absence of the upper part of the symphysis does not allow of a precise restoration of the specimen. As, however, the whole of the bone preserved closely resembles that of a young chimpanzee, it seemed reasonable to restore the fossil on this model and make the slope of the bony chin intermediate between that of the adult ape and that of *Homo heidelbergensis* (pl. 7). If this restoration proved to be correct then the alveolar border was so long that it would be necessary to assume the presence of a relatively large, though probably not very prominent canine. The two molar teeth are noteworthy for their considerable length in proportion to their width and in each being provided with a large fifth cusp. They are, although distinctly human, of the most primitive type, and must be regarded as reminiscent of the apes in their narrowness." * * *

The above were the essentials of the information we possessed about the Piltdown specimens up to recently. Meanwhile the find has been discussed at the late meeting (August, 1913) of the British Association for the Advancement of Science, as well as in some pub-

PLATE 7.
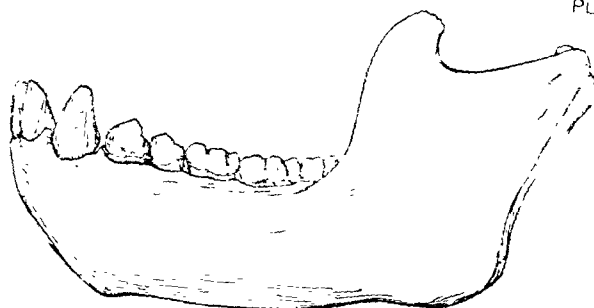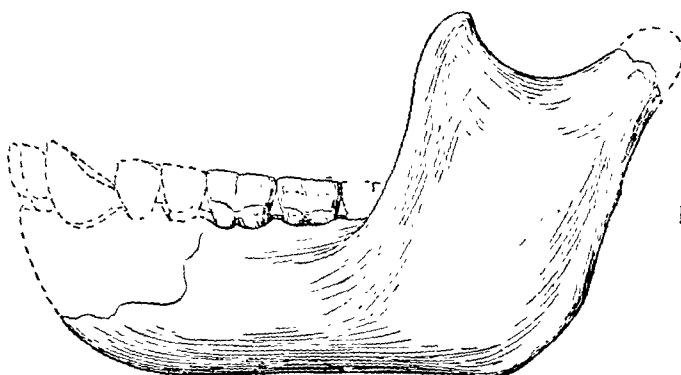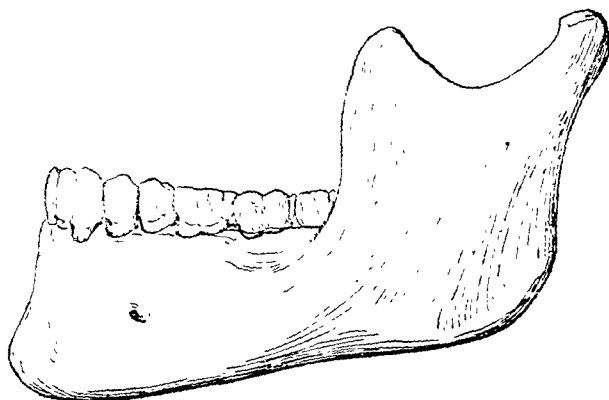
RESTORATION OF THE PILTDOWN MANDIBLE (B), COMPARED WITH THAT
OF MAN (C) AND YOUNG CHIMPANZEE (A), IN LEFT SIDE VIEW

After A. Smith Woodward.

lications, and the latest of these is another important paper by Messrs. Dawson and Woodward,[1] in which appear details of considerable additional interest. From this publication we learn that the researches by the authors in the Piltdown gravel have continued; and that the whole bed at the locality of the find was found divided into four well-defined strata. The topmost of these consists of surface soil, with pieces of iron-stained subangular flint derived from some ancient gravel and similar to the flints beneath. This surface soil also contains a mixture of pottery and implements of various ages. Beneath is the second bed of "undisturbed" gravel varying from a few inches to three feet in thickness. A paleolithic implement figured in the former paper by the writers has been found in this layer, which contains rolled and subangular flints similar to those found above and below. The third stratum, though not always present, is well marked where it does occur by reasons of its dark ferruginous appearance, and chiefly consists of pieces of ironstone and rolled and subangular flints deeply patinated and iron stained. All the fossil bones, animal and human, with the exception of the remains of a deer, were discovered in or have been traced to this third dark bed, which rests unevenly upon a fourth layer, consisting of very pale yellow, finely divided sand and clay.

The whole of the work was perforce carried on very slowly, and it was found impossible to employ more than one laborer, "for the actual excavation had to be closely watched, and each spadeful carefully examined. The gravel was then either washed with a sieve, or strewn on specially prepared ground for the rain to wash it; after which the layer thus spread was mapped out in squares, and minutely examined section by section."

While the laborer was digging the disturbed gravel within two or three feet from the spot where the mandible was found, Mr. Dawson "saw two human nasal bones lying together with the remains of a turbinated bone beneath them *in situ*." In the gravel excavated within a radius of five yards of the spot where the mandible was found, Father Teilhard de Chardin, who worked for a few days with the authors, found on August 30, 1913, a remarkable canine tooth, which, according to Messrs. Dawson and Woodward, belongs to the Eoanthropus.

There were also found in the same vicinity two evidently worked flints with a flint flake; and there were also recovered fragments of teeth of the stegodon, rhinoceros, and mastodon.

The conclusions of Messrs Dawson and Woodward are that the third or dark bed is, in the main, composed of Pliocene drift, probably reconstructed in the Pleistocene epoch.

[1] Supplementary Note on the Discovery of a Paleolithic Human Skull and Mandible at Piltdown (Sussex); Quart. Journ. Geological Society, London, April, 1914, pp 81–99.

"As regards the human remains discovered, including the canine tooth, there is nothing in their mode of occurrence to favor the idea that they may have belonged to different individuals. Putting aside the human remains and those of the beaver, the remains of the fauna all point to a characteristic land fauna of Pliocene age; and, though all are portions of hard teeth, they are rolled and broken. The human remains, on the other hand, although of much softer material, are not rolled, and the remains of beaver are in a similar condition. It would, therefore, seem that the occurrence of these two individuals belongs to one of the periods of reconstruction of this gravel, though for other reasons before stated by us, this is not perfectly certain."

The newly-found nasal bones (pl. 8) are "comparatively stout, and they are thickened at the upper border, suggesting a massive and somewhat overhanging brow ridge. * * * Comparison proves that these nasal bones resemble those of the Melanesian and African races, rather than those of the Eurasian type."

The remarkable new canine tooth (pl. 8) "is certainly that of a primate mammal, and may therefore be referred without hesitation to Eoanthropus. As it belongs to the right side of the mandible, corresponds in size with the jaw already found at the same spot, and agrees with the molar teeth in having been considerably worn by mastication, it may almost certainly be regarded as part of the specimen previously described. The crown of the tooth is conical in shape, but laterally compressed. * * * The tooth is distinctly larger than any hitherto found in genus *Homo* and differs fundamentally in having completely interlocked with its opposing tooth, which worked downward on its inner face as far as the edge of the gum. Its exact position in the jaw remains uncertain, but its crown must have risen well above the level of the other teeth, and its state of wear implies its separation from the anterior premolar by a slight diastema, as in the apes." From the various comparisons which the authors make it appear that "among known Upper Tertiary and Recent Anthropoids, the permanent lower canine of Eoanthropus agrees more closely in shape with the milk canine both of man and of the apes than with the corresponding permanent tooth in either of these groups. It is also obvious that the resemblance is greater between *Eoanthropus* and *Homo* than between the former and any known genus of apes. In other words, the permanent tooth of the extinct *Eoanthropus* is almost identical in shape with the temporary milk tooth of the existing *Homo*. Hence it forms another illustration of the well-known law in mammalian paleontology, that the permanent teeth of an ancestral race agree more closely in pattern with the milk teeth than with the permanent teeth of its modified descendants."

PLATE 8.

Smithsonian Report, 1913.—Hrdlička
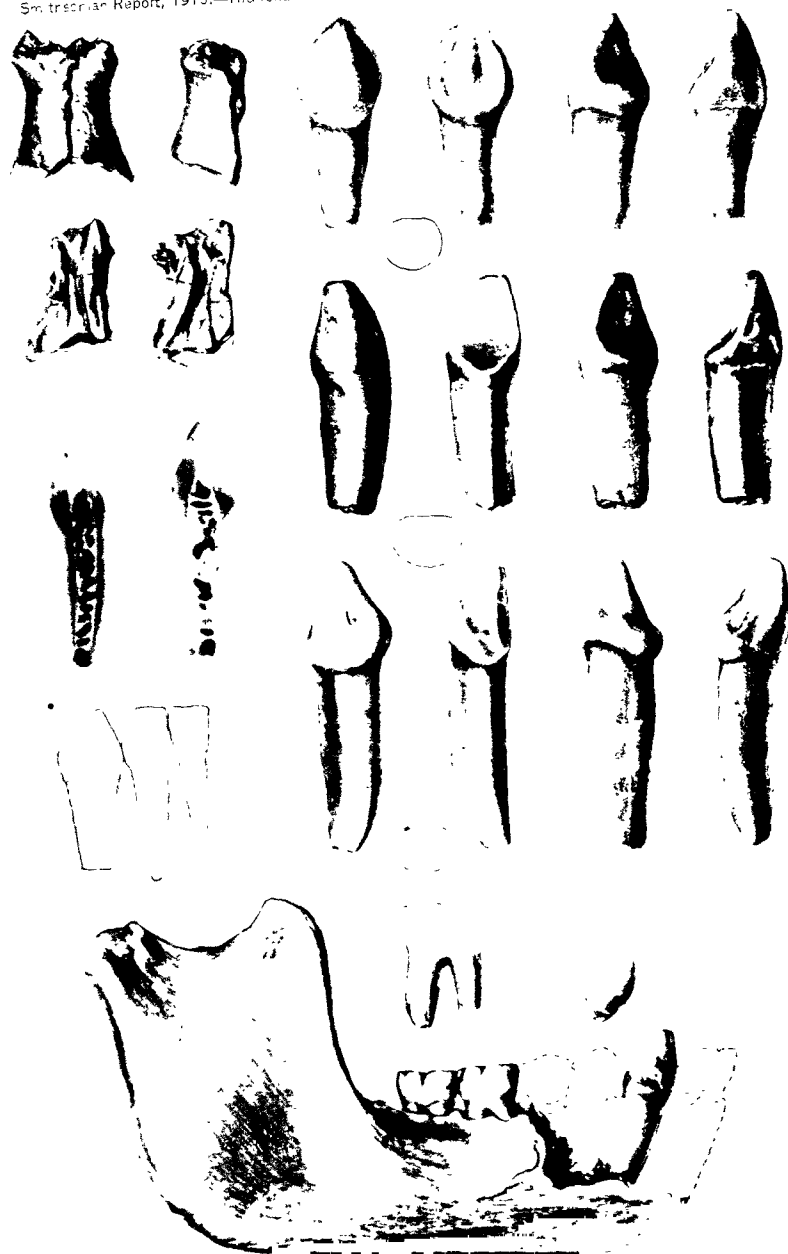
EOANTHROPUS

The newly found nasal bones and canines on various aspects and sections and the
lower jaw. After Dawson and Woodward. Quart. Jour. Geol. Soc. vol 70, pl. 15.

PLATE 9.
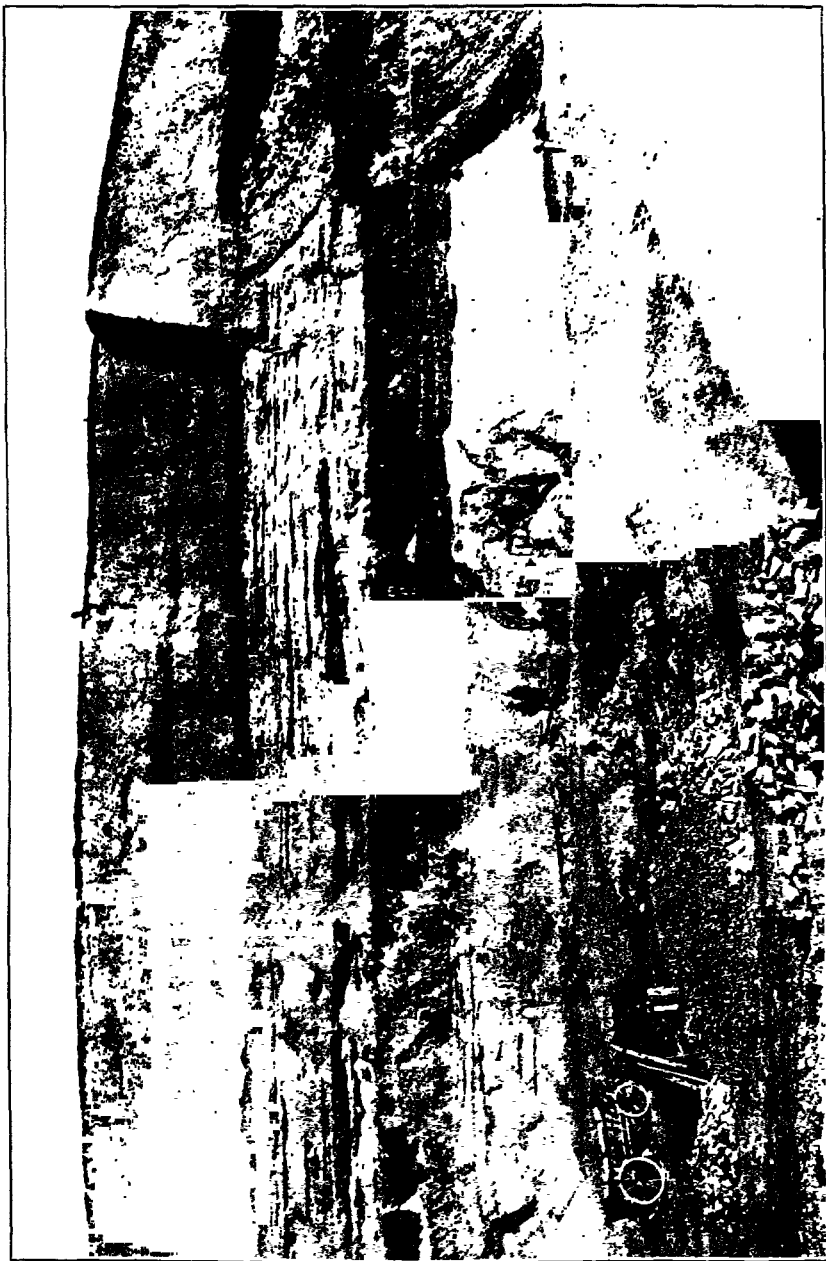
THE LOCALITY WHERE THE MAUER JAW WAS DISCOVERED.

The place where it lay, 79 feet from the surface, is marked by a white cross. (After Schoetensack.)

As to the original restoration of the skull, it appears that the changes called for by very detailed and many-sided further study, will be relatively small; and "there are reasons for believing that the individual was a young adult, and possibly a female, for the features that present secondary sexual characters in modern skulls are quite indefinite in these fragments."

Notes on an interesting discussion follow the report. There seems to be still some doubt as to the teeth belonging all to the same skull. As to the age of the remains, it can not be earlier than Pleistocene; according to Prof. W. Boyd Dawkins, this was clearly proved by the presence in the Piltdown deposits "of an antler of red deer (*Cervus elaphus*), a species unknown in the Pliocene of Europe and abundant in the Pleistocene and later strata."

Regrettably, at the time of the writer's visit in England, in the spring of 1912, the specimen was not yet available for examination by outsiders, and so no original opinion can be given concerning its status. It represents doubtless one of the most interesting finds relating to man's antiquity, though seemingly the last word has not yet been said as to its date and especially as to the physical characteristics of the being it stands for.

HOMO HEIDELBERGENSIS.

One of the oldest thoroughly authenticated skeletal relics so far discovered and attributable to a primitive human being, is the priceless specimen known as the Mauer jaw. This precious document of man's evolution is deposited in the Paleontological Institute of Heidelberg. For its preservation and thorough description we are indebted to Dr. Otto Schoetensack,[1] professor of Anthropology at Heidelberg University, who for years had been watching the finds in the sand pits near Mauer which eventually yielded the specimen. But considerable credit in this connection is due also to Herr Joseph Rösch, of Mauer, the owner of the sand pits in question, who saved the specimen from destruction, immediately called Prof. Schoetensack's attention to its discovery, and eventually donated it unselfishly to science.

The specimen, the lower jaw of an adult male, was discovered on the 21st of October, 1907, by two laborers. Both of these were still employed in the quarry at the time of the writer's visit, in June 1912, and they readily related, in company with Mr. Rösch, all the circumstances of the find.

The deposits in which the specimen was discovered are located near the village of Mauer, which lies in the picturesque Elsenz Valley, 6

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[1] Recently deceased.

miles (10 km.) southeast from Heidelberg. They form the moderately elevated undulating northern boundaries of the shallow valley, at a distance of about 2 miles from the present bed of the river, and represent in the main the quaternary accumulations of the stream. They consist of loess, sand and gravels, with here and there, in the deeper layers, isolated flat blocks of red sandstone (pl. 9).

The portion of these deposits owned by H. Rösch, located about 500 paces north of the Mauer village, have now been worked, in open manner, for upward of 30 years, in which time great quantities of building sand have been removed. During this work, particularly in the lower strata, the workingmen often unearthed fossil shells and fossil bones of various Quaternary animals. Many of these specimens found their way, mostly as gifts of Herr Rösch, to the Heidelberg University, and the diggings were repeatedly visited by scientific men, among whom Prof. Schoetensack. Both the owner and the workmen were enjoined to watch for better preserved specimens, and particularly for anything relating to the presence of man.

On the date of the find, two of the laborers were working in undisturbed material at the base of the exposure, over 80 feet in depth from the surface, when one of them suddenly brought out on his shovel part of a massive lower jaw which the implement had struck and cut in two. As the men knew it was worth while to carefully preserve all fossils, the specimen was handled with some care. • The missing half was dug out, but the crowns of four of the teeth broken by the shovel were not recovered. The men were struck at once with the remarkable resemblance of the bone to a human lower jaw: but it looked to them too thick and large to be that of man. They called Herr Rösch and he also was bewildered: but he recognized immediately that the specimen might be of considerable interest to Prof. Schoetensack and so he took charge of it. Returning to the village he telegraphed to the professor, who came the next day, and " once he got hold of the specimen, he would no more let it out of his possession." He took it to Heidelberg, cleaned it, repaired it, and in 1908 published its description in an exemplary way.[1] Since then the valuable specimen has been preserved in the Paleontological Institute of the Heidelberg University, where, thanks to the liberality of those in charge, it is available for examination to men of science.[2]

Shortly following the discovery of the jaw a most careful examination and study were made of the Mauer deposits. They were found to range from recent accumulations on the surface to Tertiary deposits in the lowest layers. The jaw lay a little less than three feet

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[1] Shoetensack, Otto. Der Unterkiefer des Homo Heidelbergensis, aus den Sanden von Mauer bei Heidelberg, 4°, Leipzig, 1908, pp. 1–67, 13 plates.

[2] The writer wishes to thank herewith especially Prof. Wilhelm Salomon, chief of the Institute, for the courtesies extended.

(0.87 meter) above the floor of the excavation and 79 feet (24.1 meters) from the surface.[1] The same level, as well as some of the higher layers, yielded fossil bones of the *Elephas antiquus*, *Rhinoceros etruscus*, *Felis leo fossilis*, and various other extinct species. The age of the human jaw has been determined by these and subsequent explorations to be earlier Quaternary, though there seems to be some uncertainty as yet as to the exact subdivision of the period to which it should be attributed.

The original specimen, when seen, impresses one at once and potently as one of the greatest anthropological treasures. It is a huge lower jaw, which looks simultaneously both human and ape (pl. 10).

It presents no abnormality or any diseased condition that could have altered it in shape, so that it may well be regarded as a perfect representative of its type. The bone is dull yellowish-white to reddish in color, with numerous small and large blackish spots. The crowns of the teeth are dirty creamy white, with blackish discolorations on the somewhat worn-off chewing surfaces of the canines and incisors, and a few similar spots over the molars; while all the parts of the teeth beneath the enamel are dull red, as if especially colored. It is much mineralized and feels more like so much limestone than bone. It weighs nearly 7 ounces (187 grams).

The jaw is considerably larger and stouter than any other known human mandible. Its ascending rami are exceedingly broad. Its coronoid processes, thin and sharp in modern man, are thick, dull, broad, and markedly diverging. The chin slopes backward as in no human being now known or thus far discovered, with the possible exception of the recently reported Eoanthropus; and there are other primitive features. The total of the characteristics of the bone are such that, had the teeth been lost, it would surely have been regarded as the mandible of some large ape rather than that of any human being.

The teeth of the Mauer jaw, however, are perfectly preserved, and though large and provided with great roots and in various other ways primitive, they are unquestionably human teeth. They force the conclusion that their possessor, while of heavy, protruding face, hugh muscles of mastication, wide and thick zygomatic arches, thick skull, probably heavy brows, and possibly not yet quite erect posture, had nevertheless already stepped over that line above which the being could be termed human. His food and probably his mode of life were related to those of primitive man, and he was already far removed from his primate ancestors with large canines.

The writer will not enter into the anatomical details of the specimen, which have been admirably brought out by Prof. Schoetensack.

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[1] The exact spot has been marked by Prof. Schoetensack with a stone monument bearing the inscription: " Fundstelle des menschlichen Unterkiefers, 21 Oktober, 1907."

The main dimensions of the bone as taken by the writer and contrasted with a modern male German jaw of average strength, are as follows:

Measurements of the Mauer jaw and those of an ordinary lower jaw of a white man of German descent.

	Mauer jaw.		German jaw.	
	Right side.	Left side.	Right side.	Left side.
Horizontal length (from the most forward point of the alveolar border in the middle, to the middle of the posterior border of the ascending ramus)	*cm.* 12.5	12.1	*cm.* 9.1	9.0
Breadth:				
Bigonial	10.8		10.0	
Bicoronoid	11.3		9.8	
Bicondylar	13.1		12.2	
Vertical height in the median line at front (the jaw reposing naturally on a horizontal surface)	5.2		4.5	
Height at middle of second molar	3.2		2.5	
Thickness (at right angle to the vertical diameter of the horizontal ramus) at median incisors and midway from above downward	1.8		.9	
At second molars	2.05		1.5	
Maximum (at third molars)	2.25		1.5	
Smallest breadth of the ascending ramus	5.2	5.0	2.8	2.7
Length of dental arch	5.85		5.4	
Breadth of the dental arch	7.05		6.4	
Length of the three molars, at insertion	3.55		3.3	

It is readily seen that the jaw exceeds considerably that of the modern man in every dimension.

The carefulness of the workingmen in the Mauer sand deposits has been redoubled since the find of the jaw, and the locality has also been subjected to considerable scientific exploration, but thus far without further result so far as human remains are concerned. No signs were discovered which would indicate that the specimen found in 1907 proceeded from a burial. Evidently it became mingled accidentally and while still fairly fresh with the ancient alluvium, wherein by rare good fortune it was perfectly preserved. There can be but little hope that other parts of the same skull or skeleton will ever be recovered; but it is not impossible that the large early accumulations of the Elsenz Valley may inclose and some day yield parts of some equally early individual which will throw further light on the physical organization of this most interesting ancient representative of humanity.

THE SKULL OF GIBRALTAR.

This highly valuable but comparatively little known specimen is preserved in the Museum of the Royal College of Surgeons, England, where, thanks to the courtesy of the curator, Prof. Arthur Keith, the writer was able to examine it and have it photographed.

The history of the specimen is, regrettably, somewhat defective. The first mention of it occurs in Falconer's Paleontological Memoirs,[1]

[1] Falconer, Hugh. Paleontological memoirs and notes, 2 vols., 8°, London, 1868; also Quart. Journ. Geol. Soc. London, vol. 21, 1865, p. 369.

PLATE 10.

THE MAUER LOWER JAW.

(After Schoetensack. About three-fourths natural size.)

PLATE 11.

THE GIBRALTAR SKULL. SIDE VIEW. ($\frac{2}{3}$.)

(Photographed for the Smithsonian Report from the original.)

in 1868, where, on page 561 of volume 2, speaking of various anthropological and other finds at Gibraltar, the author says:

One of the human skulls yielded by the rocks many years since appears to us to point to a time of very high antiquity. In fact, it is the most remarkable and perfect example of its kind now extant. In the absence of a properly organized museum no record exists of the precise circumstances under which this interesting relic was found, and that it has been preserved at all may be considered a happy accident; it has cost us much labor, and with but partial success, to endeavor to trace its history on the spot where it turned up.

Besides this Falconer remarks in a letter to a relative,[1] referring to the skull: " It is a case of a very low type of humanity—very low and savage, and of extreme antiquity—but still man   *   *   *.

Taking all the available data into consideration,[2] it appears that the skull was discovered, accidentally, as early as 1848, therefore eight years before the Neanderthal cranium made its appearance in the " Forbes Quarry, situated on the north front of the Rock of Gibraltar." According to Keith,[3] it was " quarried out of the terrace under the north face of the rock," a terrace formed of solidified breccia, consisting of the débris of weathering of the limestone cliff and fine wind-blown sand. The part of the terrace where the cranium lay was possibly in former times the floor of a cave. Part of a cave still exists behind the site of the discovery and was explored in 1911 by Duckworth, but without results. It is certain that the skull showed, and to some extent presents to this day, a hard stony matrix adhering to its surface and filling its cavities. Broca, to whom we owe the first descriptive account of the specimen [4] says that it was taken out from a " very compact and adherent gangue " out of which it was disengaged with much difficulty. The photographs published with Broca's account show still very noticeable remnants of the stony matrix (see also pl. 12).

The skull was presented to the Gibraltar Scientific Society by its that time secretary, Lieut. Flint, but for many years received no scientific attention. In 1862 it came to England, with the collections from the Gibraltar caves, and was studied to some extent by Busk and Falconer. The latter, perceiving how much it differed from recent human skulls, proposed to refer it to a distinct variety of man, the *Homo colpicus*, after Calfé, the old name of Gibraltar. In 1868 finally Busk presented the cranium to the Museum of the Royal College of Surgeons of England, where it is still preserved.

The first descriptive account of the specimen ,was published, as mentioned above, by Broca, but the adhering stony matrix pre-

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[1] Op. cit., p. 561, footnote.
[2] Compare Keith, A. The early history of the Gibraltar cranium. (Nature, 1911, pp. 313–314.)
[3] Ancient Types of Man, 1911, p. 121.
[4] Broca, P. Crânes et ossements humains des cavernes de Gibraltar. (Bull. Soc. d'Anthropol. Paris, 2d séries, vol. 4, 1869, p. 154.)

vented at that time any attempts at accurate measurements. Subsequently it received attention from Huxley, Quatrefages, and Hamy, and later from Macnamara, Klaatsch, Schwalbe, Sollas, Sera, and Keith, as well as the writer. It is a very remarkable specimen which, even though the geological and paleontological evidence relating to its antiquity is imperfect, does not allow for one moment any doubt as to its representing an early form of the human being; and its characteristics are such that it is now universally regarded as a representative, possibly a very early one, of the *Homo neanderthalensis*.

The cranium (pls. 11, 12, 13) is dirty yellowish to whitish in color. It is considerably mineralized. The stony matrix has been so far removed that all important determinations and measurements which the defective state of the bone itself permits, can now be made. A fortunate circumstance is that the frontal and facial parts are relatively well preserved; the vault on the other hand is largely defective, but even here sufficient portions remain to permit of a number of valuable determinations, and a fairly correct reconstruction.

The aspect of the face is semihuman, apish. There is a marked and quite heavy supraorbital arch, notwithstanding the fact that the skull is probably that of a female. The orbits are very spacious, especially in height, and the frontal process between, especially at the level of the superior borders of the orbits, is very stout. The nasal bridge is low, though not excessively so, and the nasal aperture is very broad. There are no suborbital (canine) fossæ—the surface of the maxillaries in this region is in fact slightly convex, as in the apes. The zygomatic arches are deficient and in consequence it is impossible to say anything definite about their breadth, except that in all probability this was considerable. The upper alveolar process is largely absorbed, so that we can not judge of the original prognathism, which however was doubtless well marked. The teeth show unusual strength and especially length, though their crowns are largely worn off.

The vault, viewed from above, is ovoid in shape and decidedly low. The forehead is low and sloping. The cranial bones are thick, exceeding any in this line that can be found in normal modern European.

The external dimensions of the skull are fairly large, but the brain was small. The cranial capacity is estimated by Keith as having been under 1,100 c. c.—that in an adult white woman of the present time averaging about 1,325 c. c. The palate was large and approached the horseshoe in shape. The fossæ for the articulation of the lower jaw are rather small and, as in the Krapina skulls to be described later, they are inclined distally more upward than in man of the actual time.
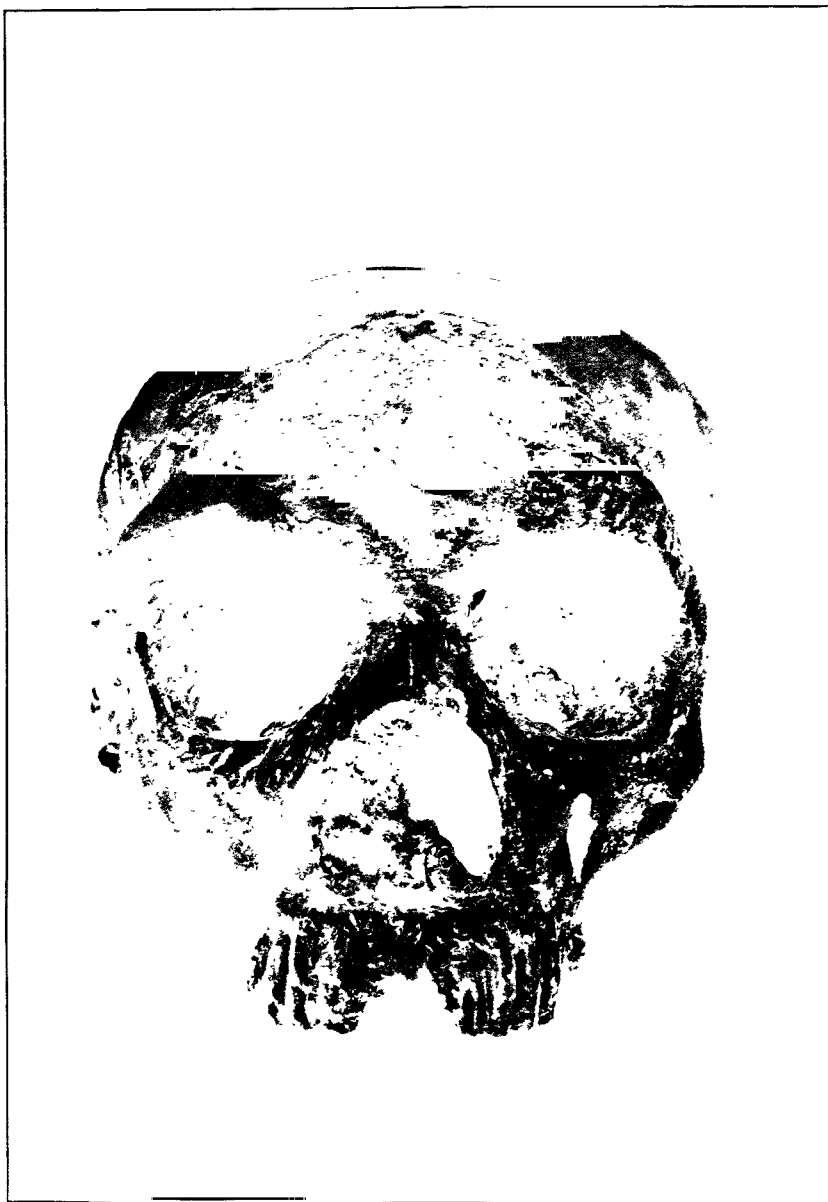
THE GIBRALTAR SKULL. FRONT VIEW.

Photographed for the Smithsonian Report from the original.

PLATE 13.
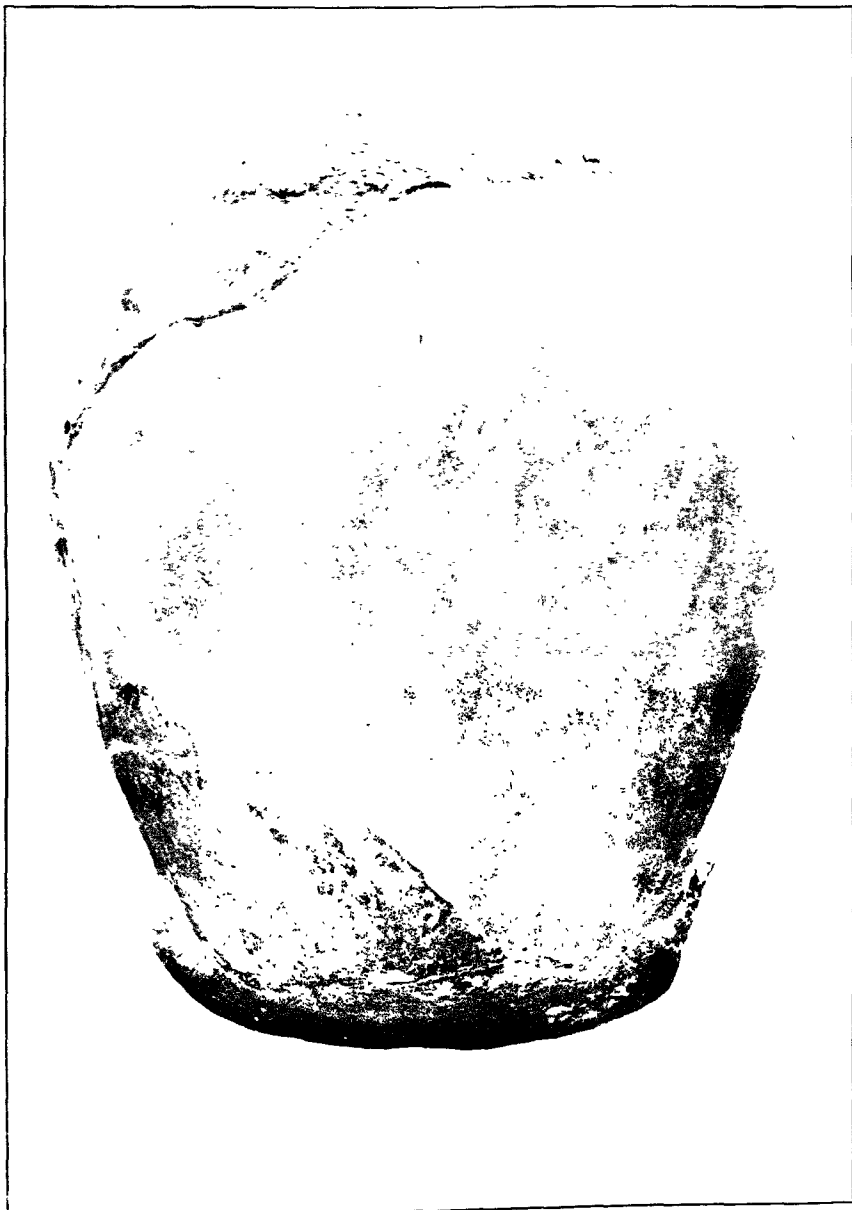
GIBRALTAR SKULL. TOP VIEW.

Photographed for the Smithsonian Report from the original)

The principal measurements which the writer secured on the specimen, and which differ slightly from those previously reported, especially as to the breadth of the skull, are as follows:

	Cm.
Length maximum (glabello-occipital)	19.3
Breadth maximum, near	14.8
Cephalic index	76 to 77
Height between a point corresponding about to the bregma and a point on the basilar process just back of the vomer	10.8
Diameter frontal minimum	9.9
Upper alveolar point to nasion, approximately	7.9
Nose height (mean of the two sides)	5.8
Breadth maximum	3.4
Palate length (Turner's method), about	7.0
Breadth, about	6.8

	Mm.
Thickness of right parietal, 1 cm. above and along the squamous suture	6.9

	Right. Cm.	Left. Cm.
Orbits, height	4	3.8
Breadth	4	4.0
Maximum length of the brain		16.4

The majority of these measurements show well the low type of the skull.

There are numerous other details and dimensions about the specimen which are of interest to the anthropologist, but which can not well be dealt with in this paper. It will suffice to say that both the visual and the instrumental examination of the specimen lead to the conclusion that the Gibraltar skull represents a highly valuable remains of an early human being and that its principal characteristics justify the classification of this ancient form with the *Homo neanderthalensis*.[1]

THE NEANDERTHAL SKULL AND BONES.

The most famous of the skeletal remains representing early man are unquestionably the imperfect but highly characteristic specimens known as the Neanderthal skull and bones. This important find more than any other has aroused scientific men to intense realization of the earlier phases of human evolution. The skull and to some extent also the other parts of the skeleton stand morphologically far below those of any existing type of man, being correspondingly nearer to the ancient primates; and their name has been deservedly taken to designate with the entire early phase of mankind of which the skeleton is, as now well known, a prototype.

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[1] ADDITIONAL REFERENCES.

SEBA, G. L. Nuove osservazioni ed induzioni sul cranio de Gibraltar. Arch. p. l'Antropol. and Etnol., vol. 39, Firenze, 1910, pp. 1–66, pls. 3–5.

SOLLAS, W. G. On the cranial and facial features of the Neanderthal race. (Philosophical Transactions, Roy. Soc. London, 1907, vol. 199B, p. 281–339.)

The skull, with other parts of the skeleton, were found in August, 1856.[1] They were dug out accidentally by two laborers from a small cave, located at the entrance of the Neanderthal gorge, in Westphalia, western Germany. The bones were given but little attention by the workmen, but fortunately news of the find reached an Elberfeld physician, Dr. Fuhlrott, and he was still able to save the skullcap, the femora, humeri, ulnæ, right radius, portion of the left pelvic bone, portion of the right scapula, piece of the right clavicle, and five pieces of ribs (see pls. 14–18).

Soon after their discovery the skeletal remains of the Neanderthal man received the attention of Prof. D. Schaaffhausen, of Bonn, who on the 4th of February, 1857, made a preliminary report upon them at the meeting of the Lower Rhine Medical and Natural History Society, of Bonn.[2] At the general meeting of the Natural History Society of Prussian Rhineland and Westphalia, at Bonn, on the 2d of June, 1857, Dr. Fuhlrott himself gave a full account of the locality of the find and of the circumstances under which the discovery was made.

The principal details of Dr. Fuhlrott's [3] report were as follows:

A small cave or grotto, high enough to admit a man and about 15 feet deep from the entrance, which is 7 or 8 feet wide, exists in the southern wall of the gorge of the Neanderthal, as it is termed, at a distance of about 100 feet from the Düssel [4] and about 60 feet above the bottom of the valley (fig. 3). In its earlier and uninjured condition this cavern opened upon a narrow plateau lying in front of it and from which the rocky wall descended almost perpendicularly to the river. It could be reached, though with difficulty, from above. The uneven floor was covered to a thickness of 4 or 5 feet with a deposit of mud, sparingly intermixed with rounded fragments of chert. In the removing of this deposit the bones were discovered. The skull was first noticed, placed nearest to the entrance of the cavern; and further in were the other bones lying in the same horizontal plane. Of this I was assured in the most positive terms by two laborers who were employed to clear out the grotto, and who were questioned by me on the spot. At first no idea was entertained of the bones being human; and it was not till several weeks after their discovery that they were recognized as such by me and placed in security. But, as the importance of the discovery was not at the time perceived, the laborers were very careless in the collecting and secured chiefly only the larger bones; and to this circumstance it may be attributed that fragments merely of the probably perfect skeleton came into my possession.

Fuhlrott held that the Neanderthal bones might be regarded as "fossil," by which he possibly meant not merely mineralized, but

[1] In many publications the date is erroneously given as 1857.

[2] Verhandl. d. naturhist. Vereins der preuss. Rheinlände und Westphalens, vol. 14. Bonn, 1857. Also "Zur Kenntniss der ältesten Rassenschädel," Müller's Archiv, 1858, p. 453 et seq.

[3] Ib. Correspondenzblatt No. 2. The above follows G. Busks's Translation of Schaaffhausen's "On the crania of the most ancient races of man," Nat. Hist. Review, April, 1861.

[4] Near Hochdal, between Elberfeld and Düsseldorf.

PLATE 14
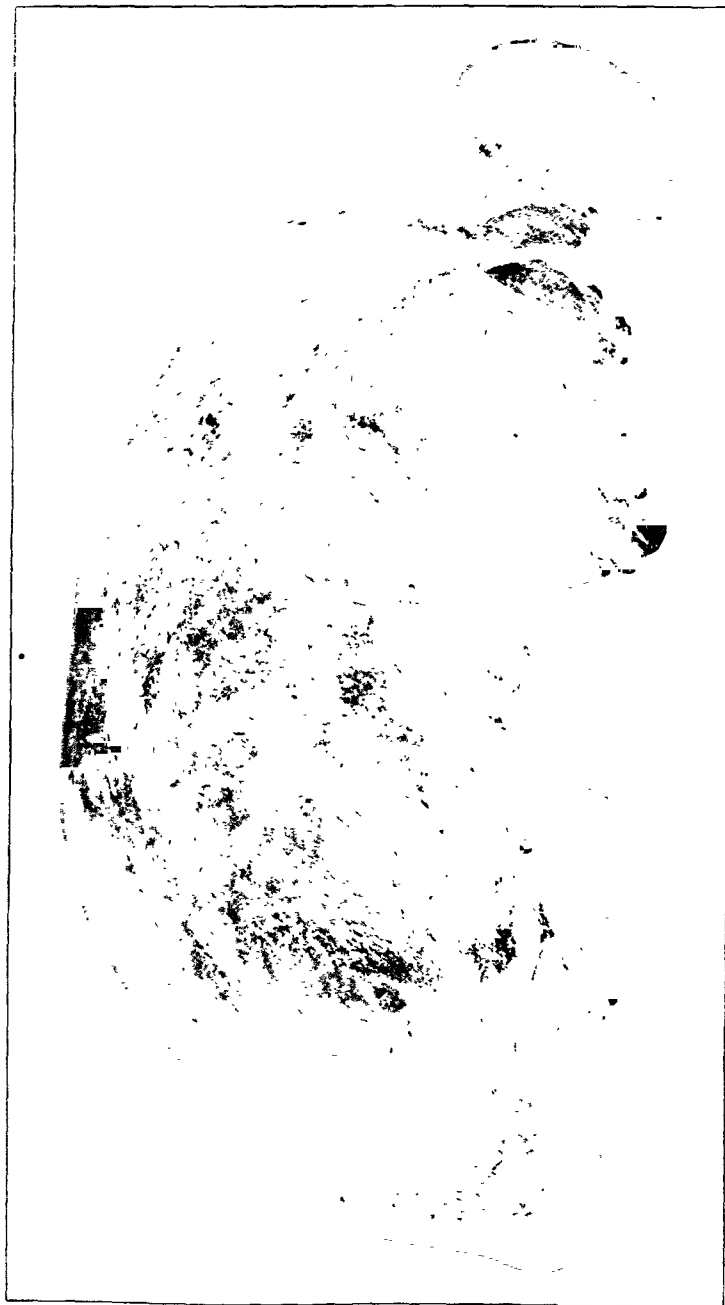
THE NEANDERTHAL SKULL.   SIDE VIEW.

(Photographed for the Smithsonian Report from the original.)

PLATE 15.
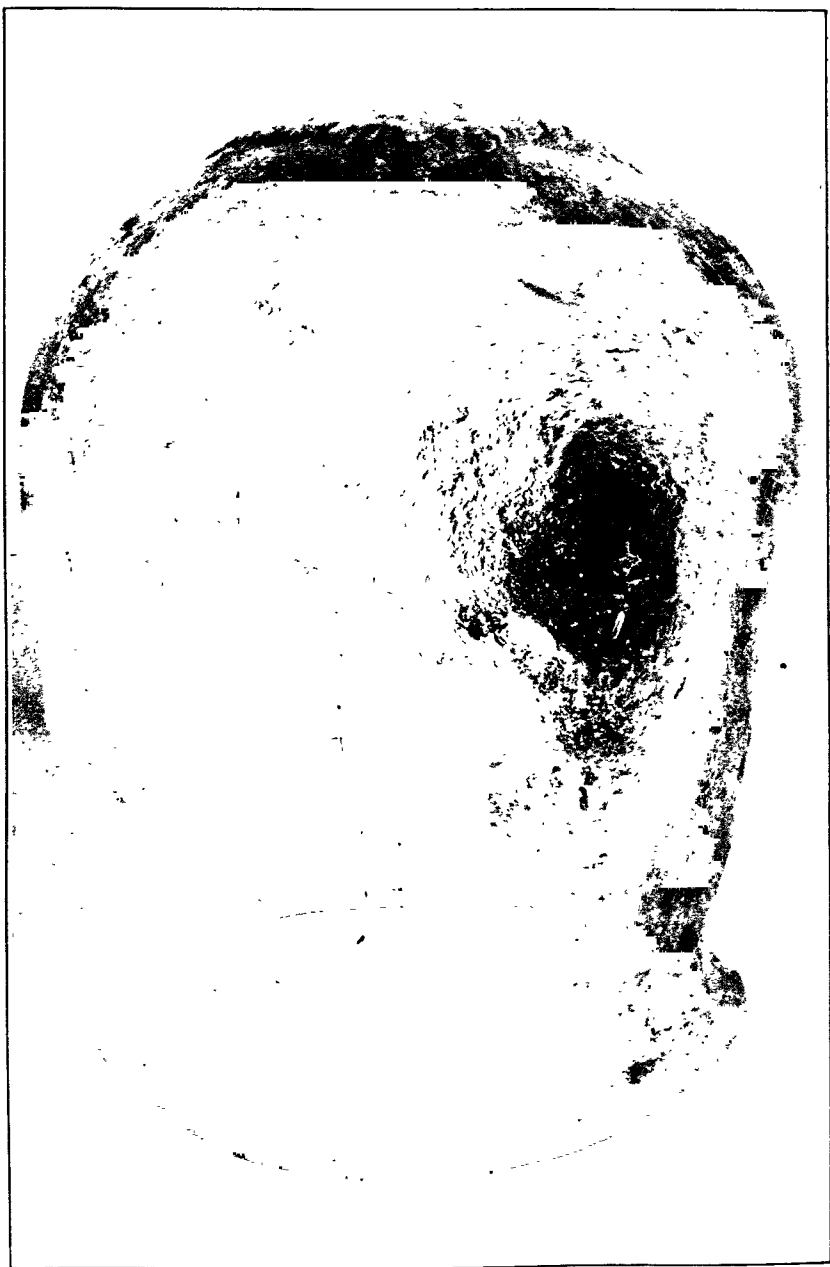
THE NEANDERTHAL SKULL. TOP VIEW.

(Photographed for the Smithsonian Report from the original.)

also belonging to a form of humanity no more existing. A little later Prof. Schaaffhausen arrived at the following conclusions:[1]

First. The extraordinary form of the skull was due to a natural conformation, hitherto not known to exist even in the most barbarous races. Second. These remarkable human remains belonged to a period antecedent to the time of the Celts and Germans, and were in all probability derived from one of the wild races of northwestern Europe. spoken of by Latin writers, and which were encountered as autochthones by the German immigrants. And third. It was beyond doubt that these human relics were traceable to a period at which the latest animals of the Diluvium still existed: though no proof of this assumption, nor consequently of their so-termed fossil condition, was afforded by the circumstances under which the bones were discovered.

In 1860 the Neanderthal cave was visited, in company with Dr. Fuhlrott, by Lyell, who made a sketch of the locality (fig. 3), and
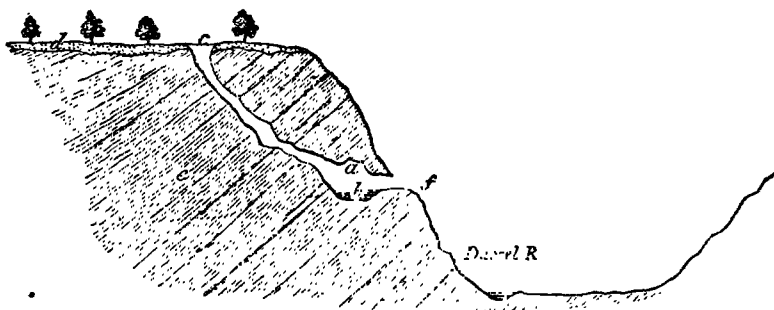
FIG. 3.—SECTION OF THE NEANDERTHAL CAVE, NEAR DÜSSELDORF. (After Lyell.)

a. Cavern 60 feet above the Düssel, and 100 feet below the surface of the country at c.
b. Loam covering the floor of the cave, near the bottom of which the human skeleton was found.
b, c. Rent connecting the cave with the upper surface of the country.
d. Superficial sandy loam.
e. Devonian limestone.
f. Terrace, or ledge of rock.

we are given the following additional information:[2] Since the discovery of the bones—

the ledge of rock, f, on which the cave opened, and which was originally 20 feet wide, had been almost entirely quarried away, and, at the rate at which the work of dilapidation was proceeding, its complete destruction seemed near at hand.

In the limestone are many fissures, one of which, still partially filled with mud and stones, is represented in the section at a c as continuous from the cave to the upper surface of the country. * * *

There was no crust of stalagmite overlying the mud in which the human skeleton was found, and no bones of other animals in the mud with the skeleton; but just before our visit in 1860 the tusk of a bear had been met with in some mud in a lateral embranchment of the cave, in a situation precisely simi-

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[1] L. c.

[2] Lyell, Sir Charles. The geological evidences of the antiquity of man, 4th ed., London, 1873, p. 80 et seq.

lar to *b*, figure 3, and on a level corresponding with that of the human skeleton. This tusk, shown us by the proprietor of the cave, was 2½ inches long and quite perfect; but whether it was referable to a recent or extinct species of bear, I could not determine.

Following the early notices concerning the Neanderthal cranium, and before other specimens of similar nature, such as the Spy, Gibraltar and others became known, an extensive controversy arose as to the real significance of the find. Virchow,[1] and after him others, were at first inclined to look upon the skull as pathological; to Barnard Davis[2] its sutures appeared to show premature synostosis; while Blake[3] and his followers regarded the specimen as probably proceeding from an idiot. But there were also those, such as Schaaffhausen, Broca, and others, who from the beginning saw in the cranium (the other bones received at first but little attention) not any pathological or accidental monstrosity, but a peculiar, thereto unknown type of ancient humanity. Then gradually new examples of this same early type appeared in different parts of Europe, under circumstances which steadily strengthened the claim of the whole class to geological antiquity; and when eventually a thorough comparative study of the Neanderthal remains was carried out by modern methods and in view of new knowledge, the cranium and bones were definitely recognized as representing, in a normal and most characteristic way, a most interesting earlier phase or variety of mankind, our mid-quarternary predecessor or close relative *Homo neanderthalensis*. The credit for deserving work in this field is due especially to Prof. G. Schwalbe, of Strassburg, whose numerous publications on the early forms of human remains in Europe are well known to every anthropologist.[4]

Notes on the specimens.—The remains of the Neanderthal skeleton are preserved in the Provincial Museum at Bonn, where, due to the courtesy of the director, Prof. Hans Lehner, the writer was enabled to examine the originals and later have them photographed.

The skull (pls. 14–16) is gray in color, with large mud-brownish patches on the outside, and whitish gray to whitish brown on the inside. It is decidedly heavy and mineralized. It is plainly nonpathological. The sagittal suture has evidently closed earlier than it ordinarily does in the modern man, but this must have taken place after the brain ceased to influence the cranial vault, for it resulted in no deformation. The coronal suture is obliterated up to the

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[1] Virchow, R.   Untersuchung des Neanderthal-Schädels. Zeit. f. Ethnol., vol. 4, 1872, Verhandl. Berl. Ges. f. Anthr., etc., pp. 157–165.

[2] Davis, J. Barnard.   On the Neanderthal skull, etc., London, 1864.

[3] Blake, C. Carter.   On the alleged peculiar characters and assumed antiquity of the human cranium from the Neanderthal. (Journ. Anthrop. Soc., London, vol. 2, 1864, pp. 139–157; also Mem. Anthrop. Soc., London, vol. 2, 1866, p. 74.)

[4] Those especially worthy of mention in this connection are: Über die Schädelformen der ältesten Menschenrassen, mit besonderer Berücksichtigung des Schädels von Egisheim. Mitteilungen der philomathischen Gesellschaft in Elsas-Lothringen. 5, Jahrg., vol. 3, 1897. Derselbe: Der Neandertalschädel. Bonner Jahrbücher, Heft 106; 72 Stn. 1 Tafel, 1901.

PLATE 16.

THE NEANDERTHAL SKULL. BACK VIEW.

(Photographed for the Smithsonian Report from the original.)

temporal ridges, while the lambdoid is still patent. Similar conditions to these are not seldom met with in the skulls of persons beyond the fiftieth year of life, and if not attended by scaphocephaly or other consequent deformation, can not be regarded as abnormal. The serration of the lambdoid suture is decidedly simpler than in the modern human skull.

The facial and basal parts are lacking. The vault shows very good dimensions in length and breadth, but is strikingly low, and the bones are considerably thicker than in the white man of to-day, so that the brain cavity was only moderate.

Besides its lowness the vault is characterized by a very decided protrusion of the whole supra-orbital region. The supra-orbital fore-structure or arch formed through this protrusion is heavier than in any other known example of the *Homo neanderthalensis*. The line from glabella to the naso-frontal articulation is relatively extensive and passes considerably backward besides downward, indicating a very marked depression at the root of the nose, not unlike that which is present in the adult gorilla. Due also to the forward extension of the supra-orbital arch, the upper parts of the planes of the orbits face very perceptibly downward, while in present man they face somewhat upward or approach the vertical. The remarkable extent of the protrusion of the supra-orbital region may be judged by the fact that the horizontal distance from the most prominent point of the glabella to the nearest point on the ventral surface of the lower frontal region measures 3 cm. The frontal process descends deep between the orbits and is exceedingly stout.

The forehead is very low and also slopes markedly backward, nevertheless it presents a moderately well-defined convexity. The sagittal region is oval from side to side, much like that in man of to-day; the occiput, however, is marked by a relatively high situation of the crest and other peculiarities. The outline of the vault, as looked at from above, is a long ovoid. The thickness of the frontal bone at the eminences is 8.5 mm.; of the left parietal, along and 1 cm. above the squamous suture, 6 to 8 mm.; these measurements are about one-third greater than those of the skull of an average modern European.

The principal external dimensions of the cranium, taken carefully with two separate instruments, were found to differ slightly from some of those recorded, but agree closely with those of Schwalbe. They are:

	Cm.
The greatest length	20.1
The greatest breadth	14.7
Cephalic index	73.1
Diameter frontal minimum	10.7
Diameter frontal maximum	12.3
Nasion-bregma diameter	11.7
Bregma-lambda diameter	10.3

The internal capacity of the skull has been estimated by Schaaff-hausen at 1,033 c. c., by Huxley at 1,230 c. c., and by Schwalbe at 1,234 c. c.

The brain which filled the skull was lower and narrower and slightly more pointed than the human brain of to-day, approaching in these features more the anthropoid form. The right frontal lobe was slightly larger and longer than the left, and the whole right hemisphere was slightly longer than that of the opposite side. In the present man it is generally the left hemisphere which is the longer, but this exception in the Neanderthal man is not necessarily of any special significance.

The long and other bones of the skeleton (pls. 17–18), so far as preserved, show many features of anthropological inferiority, demonstrating plainly that not merely the skull, but the whole body of the Neanderthal man occupied a lower evolutionary stage than that of any normal human being of the historic times. However, many of the details on these points are technical and must be reserved for another publication. The bones in general indicate a powerful musculature. They belong doubtless to a male individual. The stature of the man was about like the average of the present man in central Europe, or but slightly lower (the femora indicate, according to Manouvrier's scale, approximately 165 cm.)[1] The thigh bones, besides presenting a powerful neck with a relatively large head, show also a very mesially located minor condyle, certain peculiarities of the shaft, a small but distinct suprapatellar fossa which does not exist any more in man of this day, and a slight convexity, especially on the right, of the popliteal surface, a region which in the present man is as a rule more or less concave. The left humerus shows signs of an injury in consequence of which it doubtless remained much weaker than the right bone. The proximal end of the left ulna has also been damaged in life. The radius presents a marked functional (nonpathological) curvature.

A careful examination and comparison of the Neanderthal skull and bones can leave only one impression on the anatomist or anthropologist of to-day, which is that while individually and jointly the various parts represent a human being already far advanced above any anthropoid, they are still in many respects decidedly more primitive in form—that is, on a lower scale of evolution—than the skull and bones of any man of to-day.

The remains are unquestionably the most precious representatives of the important phase of early humanity which we now include under the name of *Homo neanderthalensis*.

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[1] Taking all the long bones of the skeleton, so far as preserved, into consideration, the calculated stature is 163.2 cm. See Boule, M., Annales de Paléontologie, vol. 7, No. 2, 1912, p. 117; also Rahon, Thèse, Paris, 1892; and Mem. Soc. d'Anthropol, Paris, vol. 4, 1893, p. 403.

PLATE 17.

THE NEANDERTHAL FEMORA, WITH PORTION OF A SCAPULA AND PELVIC BONE.

Photographed for the Smithsonian Report from the originals.

PLATE 18.
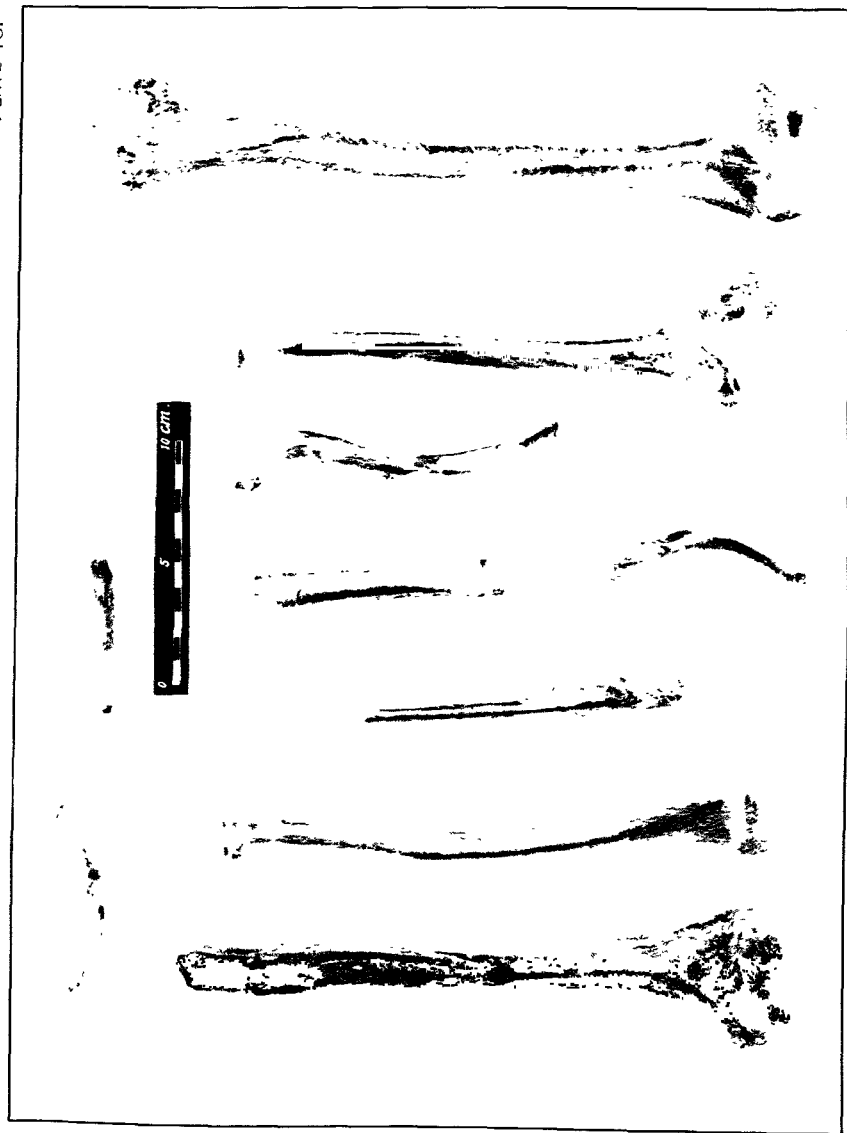
BONES FROM THE UPPER LIMBS AND THORAX OF THE NEANDERTHAL SKELETON.

(Photographed for the Smithsonian Report from the originals.)

THE SPY SKELETONS.

In June of 1886 Messrs. Marcel de Puydt, member of the Archæo-logical Institute of Liege, and Maximin Lohest, at that time assistant of geology of the University of Liege, discovered in the terrace front-ing a certain cave at Spy, in the Province of Namur, Belgium, the remains of two human skeletons associated with the débris of extinct Quaternary animals. The discovery was immediately brought to the attention of Prof. J. Fraipont, of the Liege University, and on the 16th of August, 1886, he announced the important find to the Congrès archéologique of Namur. A little later in the same year Messrs. Fraipont and Lohest published an account of the discovery, with a description of the human remains, in the Bulletins of the Royal Academy of Belgium.[1]

According to the last-mentioned account there existed in the eighties in the community of Spy, above the stream Orneau and in
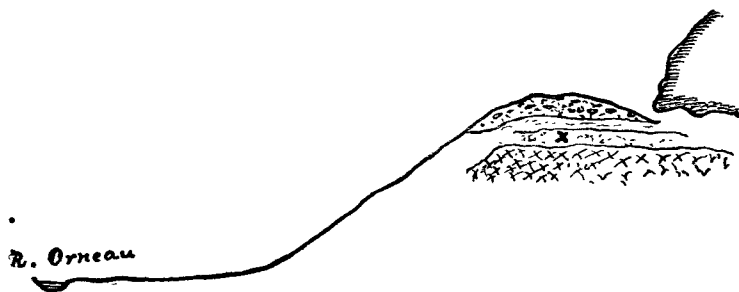
FIG. 4.—THE SPY CAVE AND TERRACE. (After Fraipont and Lohest.)
X = position of the skeletal remains of the Spy man.

the side of a wooded mountain, a cave, in which de Puydt and Lohest conducted archæological explorations since August, 1885 (fig. 4). A large terrace situated in front of the cave had not been methodically examined until 1886, and it was during excavations in this terrace that the two investigators encountered, in June of 1886, the human remains known since as the Spy skeletons.

The human bones lay in the lowest parts of the deposits, one 6, the other 8 meters in front of the entrance to the cave. They repre-sented two individuals. One of these lay on its side, the hand touch ing the lower jaw; in the case of the other the original position could not be determined.

The terrace containing the Spy skeletons was situated 14.5 meters (47.5 feet) above the shallow bed of the stream running at the foot of the mountain, and the bones lay at the depth of 13 feet from

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[1] Fraipont, J., and M. Lohest. La race humaine de Neanderthal ou de Canstadt en Belgique. Bulletins de l'Académie Royale de Belgique, 3d series, vol. 12, 1886, pp. 741–784.

the surface. The accumulations which formed the terrace included calcareous débris, various archæological traces of man's presence, and numereous remains of fossil animals. They could be separated into several strata, none of which showed any perceptible disturbance.

The layer in which the human skeletons were inclosed yielded also bones of the following fossil Quaternary mammals:

Rhinoceros tichorhinus (abundant).
Equus caballus (very abundant).
Cervus elaphus (rare).
Cervus tarandus (very rare).
Bos primigenius (fairly abundant).
Elephas primigenius (common).
Ursus spelæus (rare).
Meles Taxus (rare).
Hyæna spelæa (abundant).

This layer further contained a sliver of an animal bone which showed a crude adaptation for use, and worked stones of inferior workmanship, referable to the Mousterian period. The layer immediately above, undoubtedly of lesser age, gave besides the bones of similar fossil animals also those of a few living species. several thousands worked flints, some of which still of the Mousterian type, many worked bones including arrow points, and also fragments of pottery.

Considering the animal and archæological remains associated with the human skeletons, together with the absence of disturbance in the superimposed more recent layers, Lohest believed himself justified to refer the Spy remains to the Mousterian period; and the deductions of Fraipont. based on the study of the skeletal remains themselves. were that they belonged to the Neanderthal man. Since then the Spy remains have received careful consideration by every student of early man and the above classification was found to need no radical revision.

What remains of the Spy skeletons is preserved[1] in the collections of the University of Liege, where. thanks to the courtesies of Messrs. M. Lohest, Charles Fraipont and J. Sérvais, the writer was enabled to examine the originals.

The skeletons are currently known as No. 1 and No. 2. The remains of No. 1 comprise the vault of the skull; two portions of the upper jaw, with five molars and four other teeth; a nearly complete lower jaw, with all (16) teeth: the left clavicle; the right humerus. which has lost its upper epiphysis, and the shaft of the left humerus; the left radius, without lower epiphysis; the heads of the two ulnæ; a nearly complete right femur; the complete left tibia; and the right os calcis. The parts that have been identified as belonging to the second subject are the vault of the skull, two portions of the upper

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[1] Was, up to the invasion in 1914.

PLATE 19.

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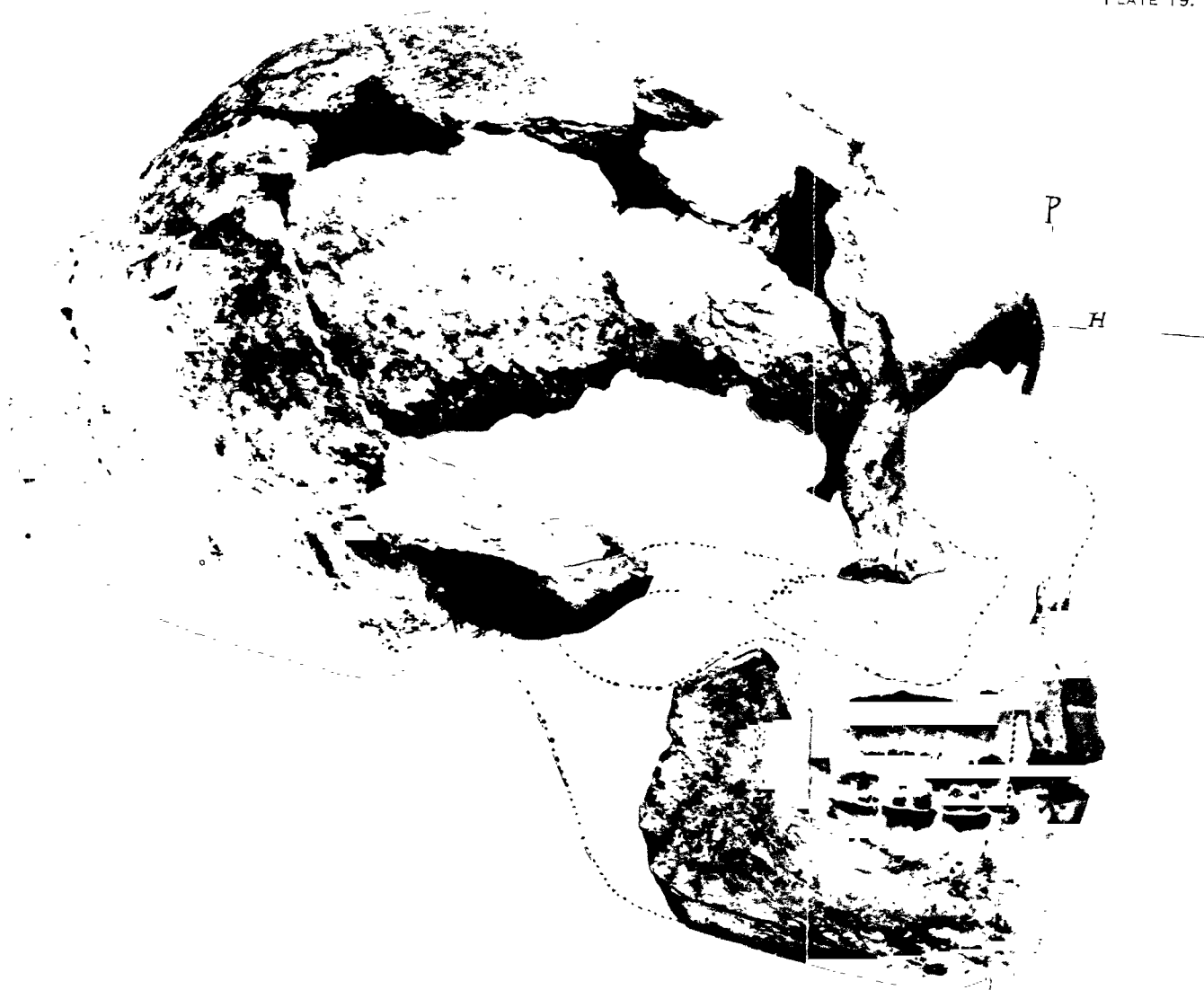
SPY SKULL No. 1. SIDE VIEW.

(After Fraipont)

maxilla with teeth, two fragments of the lower jaw with teeth, some loose teeth belonging to the lower jaw, fragments of the scapulæ and left clavicle, imperfect humeri, the shaft of the right radius, portions of the ulnæ, the left femur without its lower extremity, the left os calcis, and the left astragalus. The separation as here given needs, however, a careful revision. Besides the above, there are a number of vertebræ and small bones of hands and feet about which it is impossible to say to which skeleton they belong.

All the skeletal pieces show an advanced state of mineralization. In color they range from brownish to dark grayish, skull No. 1 representing the former and No. 2 the latter shading; the teeth, however, are quite white, with yellowish roots, much as in crania from relatively modern burials.

The bones of skeleton No. 1 are in general weaker than those of No. 2, but whether this is due to sexual difference of the two individuals, or is merely accidental, is difficult to determine. No. 2 was of a decidedly powerful musculature. The stature of the Spy man, so far as it can be determined from these remaining bones, was slightly less than that of the Neanderthal man and somewhat below the medium of white man of central Europe of the present day.

The bones of the vault in the two skulls are thicker than in the average man of the present day, though slightly less so than in the Neanderthal cranium. The sutures in both are patent with the exception of the coronal in No. 1, which shows commencement of obliteration; their serration is very simple.

The two skulls are plainly normal specimens, free from disease or deformation, and belonged to adults, approaching in No. 1 middle age, while No. 2 was younger. Somatologically they are remarkable for their important resemblances as well as differences. They belong to one type, but represent individual variations of this type that stand far apart.

No. 1 (pls. 19–20) is almost a replica of the Neanderthal cranium. There is a similarly prominent, though not quite as heavy, supraorbital arch; the forehead is even a trace lower and a trace more sloping than in the Neanderthal skull, and the general shape of the vault is much the same. The vault is also very low, but the sagittal region shows a slightly more perceptible elevation than that in the Neanderthal specimen (fig. 5).

Skull No. 2 on the other hand, while possessing similar prominent supra-orbital arch as No. 1, has a considerably higher and more convex forehead, the whole vault is higher as well as more spacious, and the form approaches in many respects that in modern man (pl. 21). The brain cavity in No. 1 is anteriorly low and relatively narrower, as well as somewhat more pointed, than in recent human crania; in No. 2 these features are also more like those in the present man.
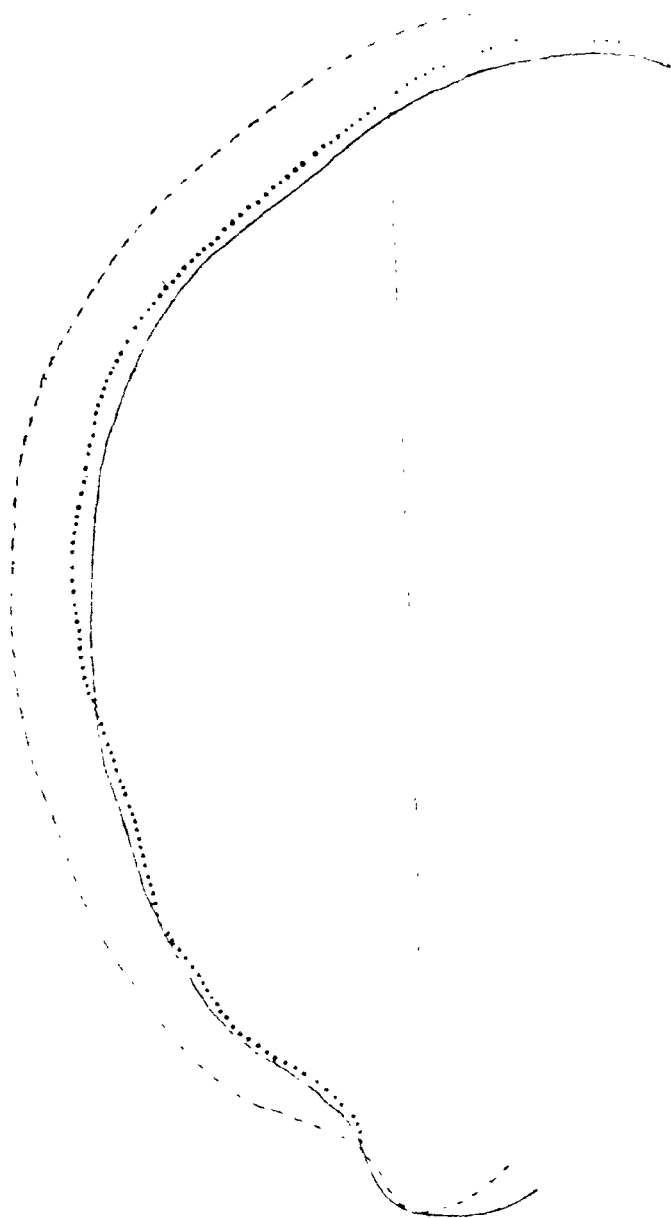
FIG. 5.—PROFILES OF THE NEANDERTHAL AND SPY CRANIA, SUPERIMPOSED. (After Fraipont and Lohest.)

———— Neanderthal.   ·········· Spy No. 1.   – – – – Spy No. 2.

PLATE 20.

Smithsonian Report, 1913 — Hrdlička

SIDE VIEW OF SPY SKULL NO. 1.

(After Fraipont and Lohest.)

PLATE 21.

SIDE VIEW OF SPY SKULL No. 2.

(After Fraipont and Lohest.)

On the whole it may be said that No. 2, while in some respects still very primitive, represents morphologically a decided step from the Neanderthaloid to the present-day type of the human cranium.
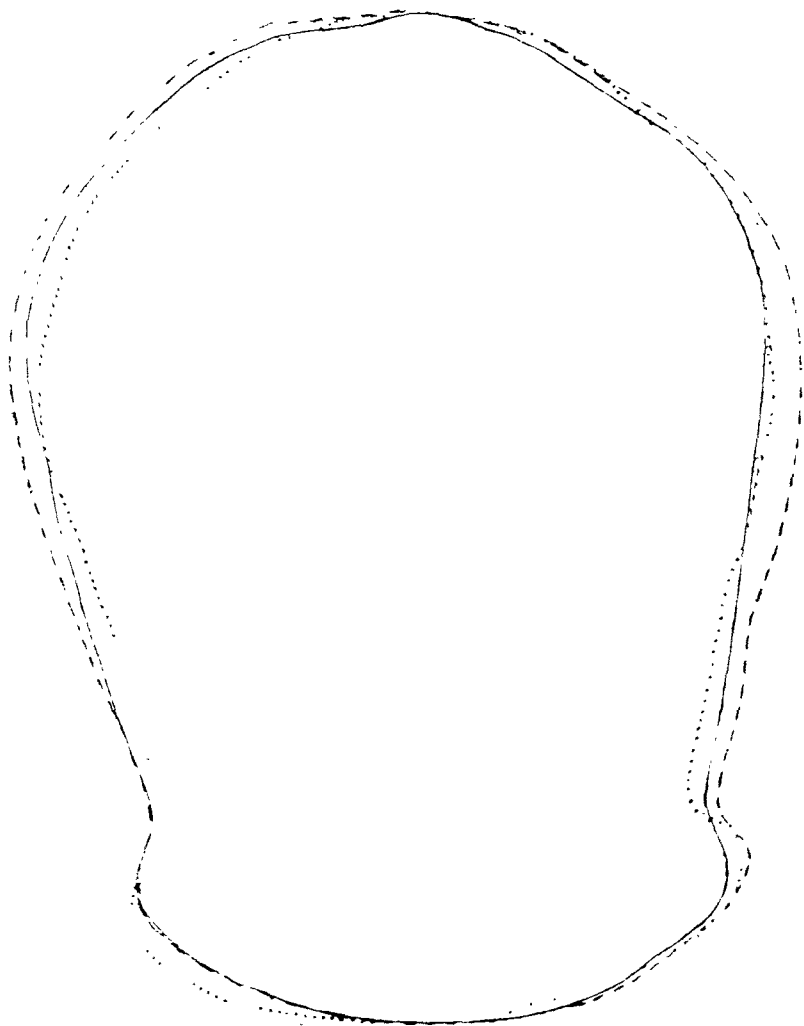
FIG. 6.—SUPERPOSITION OF NORMA VERTICALIS OF THE SPY NO. 1 AND NO. 2, AND THE NEANDERTHAL CRANIA.

——— Neanderthal.   .... Spy No. 1.   - - - - - Spy No. 2.

The lower jaw of No. 1 (pls. 19, 22), while yet of a primitive form, possesses nevertheless already a trace of the chin prominence, and in size and anatomical characteristics is closer to the present-day form

than any of the other known lower jaws dating from the Mousterian period; and the same is true of the teeth which, though considerably worn, were evidently much like human teeth of to-day.

The outline of the two skulls when viewed from above is a long ovoid in No. 1, a shorter ovoid in No. 2 (fig. 6). The principal dimensions of the two specimens as secured by the writer are as follows:

	No. 1. Cm.	No. 2. Cm.
Length, maximum, from glabella	20.3	20 (?)
Length from ophryon	18.8	18.6
Breadth maximum	14.7	15.4
Cephalic index	72.4	[1]77
Diameter frontal minimum	10.3	10.9
Nasion bregma diameter	10.6	(?)
Diameter bregma-lambda	11.3	10.8
	Mm.	Mm.
Thickness of the left parietal along and 1 cm. above the squamous suture	6 to 8	5 to 8
Thickness of the frontal at the eminences	9	8
	Cm.	Cm.
Height of lower jaw at symphisis	3.55	------
Thickness at symphisis (excluding genial tubercle)	1.3	------
Thickness at second molar	1.5	[2]1.4
Maximum thickness (opposite third molar)	1.7	1.6

A careful consideration of the evidence presented by the· two crania leads the writer to a slightly modified conclusion from the one generally accepted. The specimens are justly classified with the *Homo neanderthalensis;* but the characteristics of the lower jaw, the rising sagittal region in No. 1, and the whole shape of No. 2, barring the supraorbital arch, indicate a morphological advancement in the direction of the present type of man such as is not met with in other examples of *Homo neanderthalensis.* The crania, and particularly No. 2, may be justly regarded, it seems, as approaching transitional forms from the more typical older Neanderthal type toward that which we now know from the Aurignacean and perhaps lower Solutrean epochs, such as the *Homo aurignacensis* and the man of Předmost.

Remarks on other skeletal parts from the Spy terrace will be limited to those of skeleton No. 2, the parts representing skeleton No. 1 being fewer in number and for the most part very defective. The bones of No. 2 are massive and show many primitive features, in which they approach closely to the skeleton from the Neanderthal cave. The femur is equally characterized by very stout neck and large head, the popliteal space is still slightly convex from side to

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[1] Approximately.   [2] Fragment.
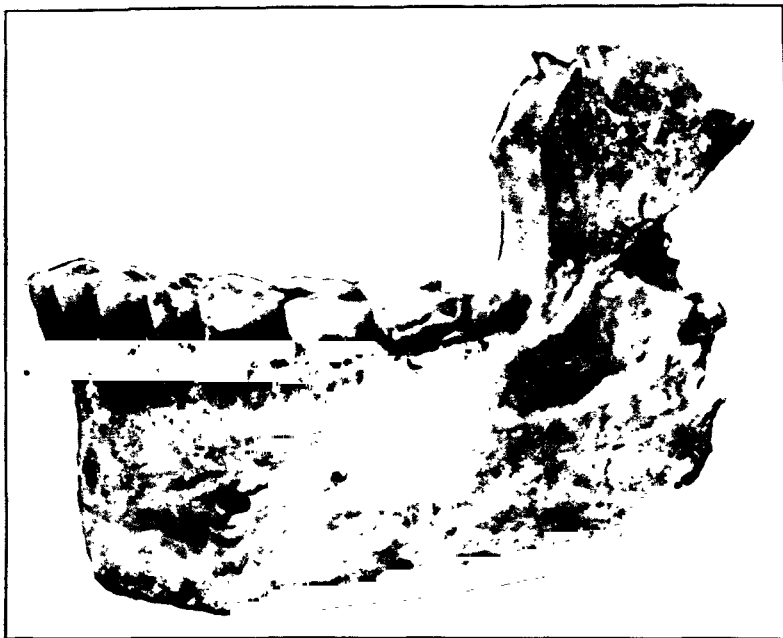
THE LOWER JAW OF SPY SKULL NO. 1.

(After Fraipont and Lohest.)

side. There is no isolated suprapatellar fossa as in the Neanderthal femur, but the ordinary lower suprapatellar depression is very pronounced. The curvatures of the femur, the characteristics of its condyles, and the marked backward inclination of the internal condyle of the tibia, differ all more or less from similar features in modern man and indicate habits of posture that have since been abandoned. The right femur (left broken) measures in bicondylar length 42.4 cm., in maximum length, 42.6; while the relatively short left tibia measures, less the spine, 33.3 cm. These dimensions correspond according to Manouvrier's tables to the stature of 161.1 cm. for the femur and 157 cm. for the tibia, or about 159 cm. (a little over 5 feet 3 inches) for the two bones together. The right femur of the Neanderthal skeleton, measured in the same manner, gave the writer 43.7, the left 43.9 cm., which shows that the Spy man was in all probability somewhat shorter. Prof. Boule, in his Annales de Paleontologie, (vol. 7, 1912, p. 117), estimates the stature of the Spy man as identical (or 1 millimeter higher) with that of the Neanderthal man, but this is evidently based on erroneous data concerning the length of the bones. However, even the most precise estimates in this line can only be gross though useful approximations, for we know but little of the length of the trunk in these skeletons, and the posture of the body in the early representatives of humanity was probably less erect than it is in man to-day.

The remaining bones of the Spy skeletons show various anatomical peculiarities and secondary primitive features, but these call for a technical description and comparisons. A rather unexpected condition, found since in other skeletons of *Homo neanderthalensis*, is the relative shortness of the forearms, as well as the legs. The radius shows a marked nonpathological curvature; and there are a number of interesting characteristics on the astragalus, which has recently been studied with much detail by the son of Julien Fraipont.[1]

The region that has given us the Spy skeletons has yielded no additional remains of similar nature, but the terrain can scarcely be regarded as exhausted by exploration.

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[1] The following works may be consulted in this connection :

Julien Fraipont et M. Lohest, Recherches sur les ossements humains découverts dans les dépôts quaternaires d'une grotte à Spy et détermination de leur âge géologique. Archives de biologie, tome 6, Gand. 1887; Fraipont, J.—Le tibia dans la race de Neanderthal. Revue d'anthropologie, Paris, 3d series, vol. 3, 1888, p. 145 et seq. Klaatsch, H.—Erg. d. Anat. u. Entwickelungsgesch, Bd. 9, 1899—Derselbe, Die wichtigsten Variationen am Skelett der freien unteren Extremität des Menschen und ihre Bedeutung für das Abstammungsproblem. ibid., Bd. 10, 1900; Fraipont, Charles—L'astragale de l'Homme Moustérien de Spy; ses affinités. Bulletin de la Société d'Anthropologie de Bruxelles, vol. 31, 1912, pp. 1–30, 3 pls.: do.—Sur l'Importance des caractères de l'astragale chez l'Homme fossile. Thèse, Univers. de Liège, 8°, Bruxelles, 1913, pp. 1–66, 6 pls.

THE DILUVIAL MAN OF KRAPINA.

One of the most important finds relating to the *Homo neandertha-lensis* is unquestionably that of the Krapina cave, in northern Croatia. It comprises a whole series of human bones of well-determined age, and the remains were not recovered accidentally or by ignorant laborers, but through prolonged, painstaking exploration. The bones themselves are for the most part fragmentary, which is much to be regretted, but they represent numerous individuals, and they show on one hand such similarities and on the other such variation of
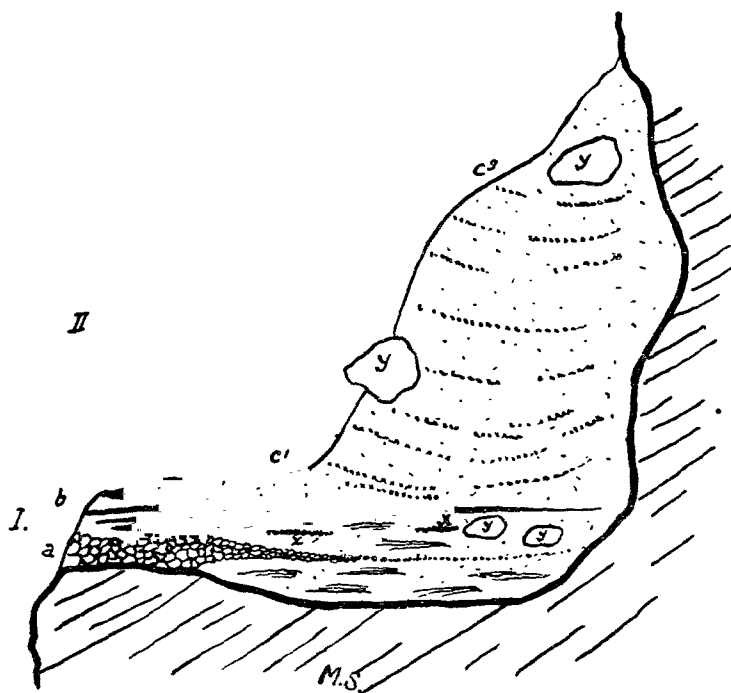
FIG 7.—A SCHEMATIC VIEW, IN TRANSVERSE SECTION, OF THE KRAPINA HOLLOW. (After Gorjanović Kramberger.)

M. S. = Mediterranean sandstone: I, the lower deposits, mostly pebbles (a) and aluvium (b), with fireplaces (x) and some large pieces of sandstone (y); II, the upper strata, composed of disintegrated rock and (c¹, c⁴) cultural remains.

structure, that they are of the greatest value to the student of ancient humanity.

The Krapina cave or more properly rock shelter, is an ancient, not very deep hollow, worn out in sandstone rock by the small stream Krapinica, and subsequently filled with water-worn stones and al-luvia brought in during overflows of the stream, together with detri-tus resulting from the decomposing rock (fig. 7). Since the forma-tion of the hollow, the Krapinica has cut its channel so that it now

PLATE 23.

Smithsonian Report, 1913.—Hrdlička

KRAPINA SKULL "C." SIDE VIEW

(After Gorjanović-Kramberger.)

PLATE 24.

KRAPINA SKULL "C." FRONT VIEW.

(After Gorjanović-Kramberger)

flows 82 feet (25 meters) below the cave. Before and while the shelter was being filled up it was utilized by the early man of the region, at first but occasionally, later for some time perhaps continuously, and the accumulations in the cave were augmented by the remains of fireplaces, by refuse including many primitive stone implements and rejects as well as animal bones, and also by numerous human bones in more or less fragmentary condition.

The locality became known in 1895, after two Croatian teachers discovered in the superficial deposits of the cave some teeth of rhinoceros and fragments of other fossil bones. These finds were brought to the attention of some of the scientific men at Zagreb (Agram), but no thorough examination of the site was undertaken until 1899. In that year the place was visited by Dr. K. Gorjanović-Kramberger, professor of geology and paleontology in the University of Zagreb and the director of the geological division of the Narodni Muzej of Zagreb, Croatia; and on excavation it was soon found that the Krapina hollow was in all probability one of the stations of early man and as such deserved a thorough exploration. Such exploration was begun without delay and was carried on, with some interruptions, until 1905, when the contents of the shelter became exhausted.

The careful explorations just referred to yielded quantities of precious paleontological and paleoanthropological material, which now fill several cases of the National Croatian Museum; and much of this material has since been thoroughly described by Prof. Gorjanović-Kramberger and reported in numerous publications.[1]

The collections consist of several thousands of various fossil animal bones, mostly fragmentary, but some well preserved; of hundreds of stone flakes the rejects of stone manufacture, and of stone implements; and of parts of human bones proceeding from at least 14 skeletons.

The animal bones represent either totally extinct forms or species now extinct in Croatia. The most common are those of *Rhinoceros Merckii*, *Ursus spelaeus*, and *Bos primigenius*. By these remains the age of the deposits has been determined as earlier Diluvial (i. e. *interglacial*), corresponding in all probability to the latter part of the Mousterian culture epoch in western Europe. The stone implements belong to the Mousterian and earlier types.

Due to the courtesy of Prof. Gorjanović-Kramberger and Dr. F. Šulje, of the Geological Division at the Narodni Muzej in Zagreb, the writer was privileged, in June, 1912, to examine the Krapina originals. This was not done with any need or hope of adding any-

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[1] Particularly in the large monograph, by K. Gorjanović-Kramberger: " Der Diluviale Mensch von Krapina in Kroatien," 4°, Wiesbaden, 1906, pp. 1-277, 52 figs., 14 pls. This memoir includes all literature on the subject up to 1906.

thing to Prof. Gorjanović-Kramberger's thorough description of the specimens, but rather because the view and handling of the original objects in a case of this importance is a rare treat which helps to fix in the mind, more than any description could, their extraordinary characteristics.

The human bones are, for the most part, in fragments. Notwithstanding their defective condition, however, the collection impresses the student most forcibly by its scientific importance. As in the case of the Mauer jaw and a number of other specimens derived from early man in Europe, the material bears the unmistakable stamp of genuineness and preciousness to anthropology, impressions which are wanting in the case of so many of the finds that are merely urged as ancient.

The bones represent, as already mentioned, the remains of at least 14 individuals of both sexes, ranging from childhood to ripe adult age. The fragmentation of the skulls (pls. 23–25) lower jaws and some of the long bones is excessive, and of such a nature as to suggest that it was caused otherwise than by accidental breaking or crushing. A number of the fragments show also the effects of burning, and one specimen, a portion of the supraorbital part of a frontal, presents some cuts. These different conditions, together with the absence of many parts of the skulls and bones, with total lack of association of the fragments and the commingling of the human with the animal bones, led Gorjanović-Kramberger to the opinion that the remains represent the leavings of occasional cannibalistic feasts and are not burials.

The Krapina bones are whitish, yellowish, or light brownish in color. They are not of great weight, but a chemical examination has shown that they are much altered in constitution, particularly in the fluorine-phosphates proportions. They may be roughly divided into the parts representing the vault of the skull; the jaws and the teeth; and other bones of the skeleton than the cranium.

The long and other bones of the skeleton, relatively less interesting than the skulls and jaws, show the Krapina man to have been, as compared with central European white man of to-day, of moderate stature, and outside of the powerful jaws, of strong though not excessive muscular development. Some individuals were very perceptibly weaker than others. As to form, particularly in the upper extremities, the bones in general are perceptibly more modern in type than those of the Neanderthal or Spy man, nevertheless they present, as well shown by Prof. Gorjanović-Kramberger, numerous and important primitive features.

The fragments of the skulls show that the bones of the vault were considerably thicker than they are in the white man of to-day. The crania were of good size externally, but the brain cavities were prob-

PHOTOGRAPH OF THE REMAINS OF KRAPINA SKULL "C," FROM ABOVE

After Gorjanović-Kramberger.

a

b
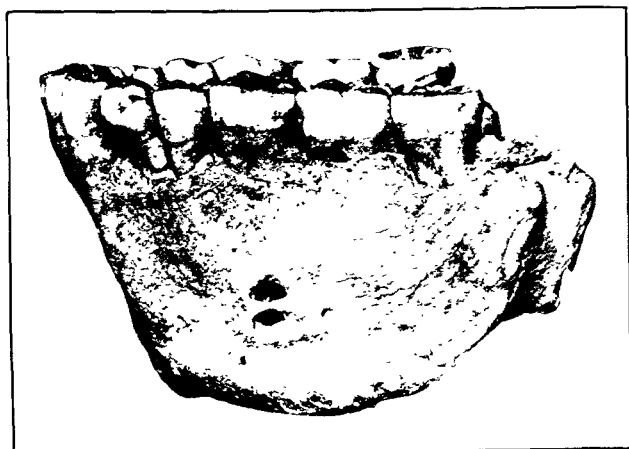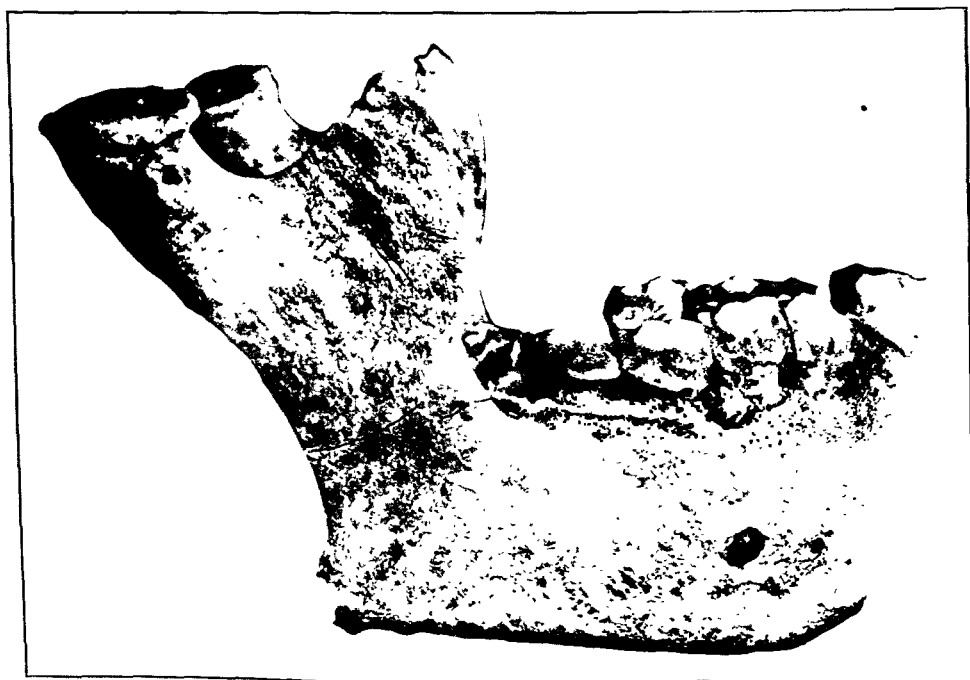
a. KRAPINA LOWER JAW "H."   *b.* KRAPINA LOWER JAW "I."

AFTER GORJANOVIĆ KRAMBERGER

ably below the present average. The vault of the skull was of good length and at the same time fairly broad, so that the cephalic index,
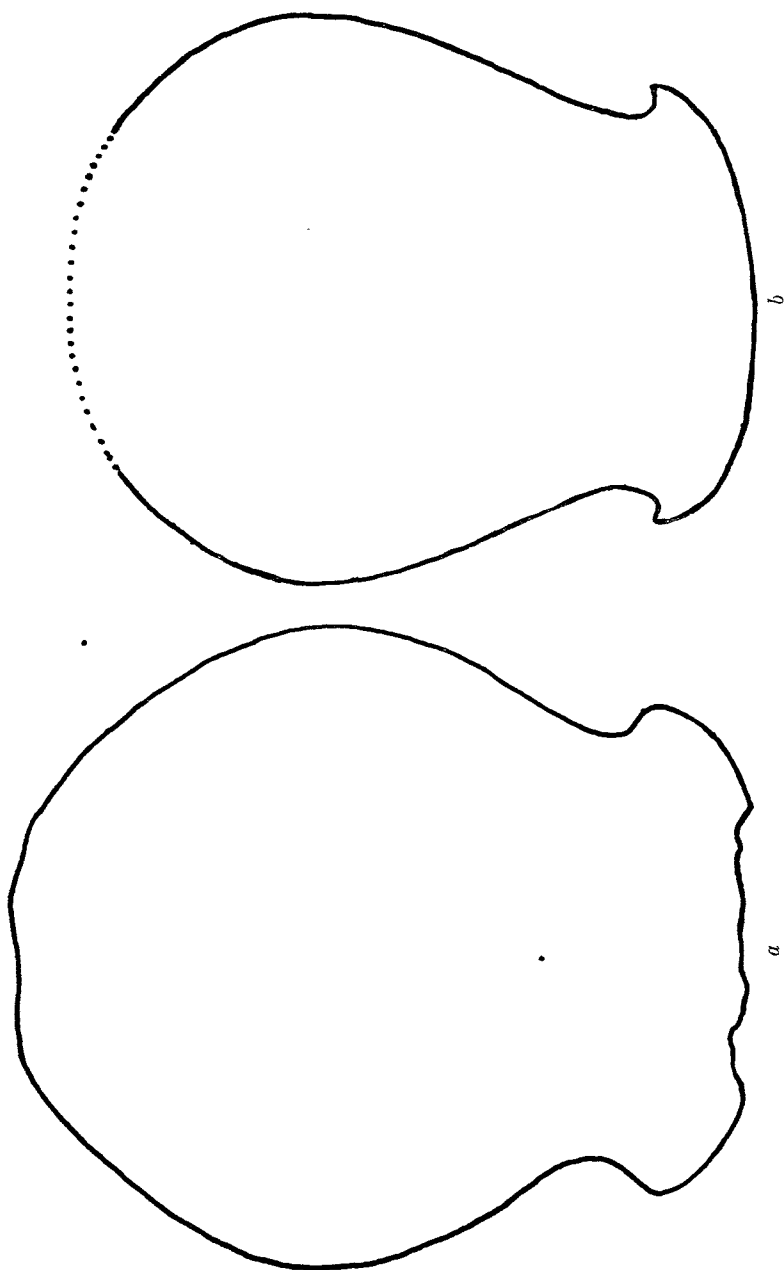
FIG. 8.—*a*, OUTLINE OF KRAPINA SKULL "*D*" (RECONSTRUCTED) AS SEEN FROM ABOVE. *b*, OUTLINE OF KRAPINA SKULL "*C*" (RECONSTRUCTED) AS SEEN FROM ABOVE. (After Gorjanović-Kramberger.)

at least in some of the individuals, was more elevated than usual in the crania of early man (fig. 8). They were also characterized, as the

Neanderthal and other crania of the man from the Mousterian epoch, by lowness of the vault, and in every instance among the adults by a pronounced, complete supraorbital arc. The last-named feature, though less marked, is plainly distinguishable even in the children. Its invariable presence is a definite proof of the fact, not quite well established before, that this arc was up to a certain phase of the Quaternary period a regular characteristic of the early man of a large part of Europe.

A number of interesting features are presented by the fragments of the temporals. The mastoids are less developed than in man of to-day, approaching correspondingly the anthropoid form. They are rather slender and small, even in the adult male. The tympanic ring, on the other hand, is massive; and the glenoid fossæ are not horizontal or nearly so, as in man of to-day, but are very perceptibly slanting in such a manner that their distal end is decidedly higher than the mesial. Many of these features connect the Krapina man directly or indirectly with earlier primate forms, and have since become largely reduced or eliminated in the human skull.

The jaws (pls. 26, 27) and teeth, like other cranial parts, present many marks of less advanced stage of evolution. The lower jaws in particular are very interesting. The symphisis or fore part of these bones, while possessing already a faint trace of the future chin eminence, slopes invariably more or less downward and backward, thus approaching the form of the mandible in apes (pls. 26, 27). The bones are massive and in males very high. They are akin to the lower jaws of the La Quina and La Chapelle skulls, and represent decidedly more primitive forms than the mandibulæ of any man of historic times, though they are considerably nearer to the modern type than the jaw of Mauer.

Of the upper maxilla there are eight or nine imperfect specimens, the majority from young subjects. They differ in development and conformation, but primitive characteristics are numerous. One of the best-preserved fragments, marked " E " or " 19 " proceeding probably from a male adolescent and representing the part of the jaw from the right median incisor to the left second premolar, shows considerable height of the bone, a straight and considerably prognathic alveolar process, a very spacious high palate, pronounced subnasal fossæ, and broad nasal aperture.

The teeth of the Krapina man offer numerous peculiarities most of which point to lower stages of differentiation (pl. 28). They are in general very perceptibly larger than those of the modern white man; their roots, especially, are longer; and there are various details of form, particularly in the crowns of the incisors and molars, some of which are related to anthropoid features. Notwithstanding these facts. the Krapina teeth, and particularly the canines, are on the whole relatively near those of present man.

a

b

a KRAPINA LOWER JAW "H," FROM APPROXIMATELY A 13-YEAR-OLD CHILD.
b KRAPINA LOWER JAW "C," FROM ABOVE

After Gorjanović-Kramberger
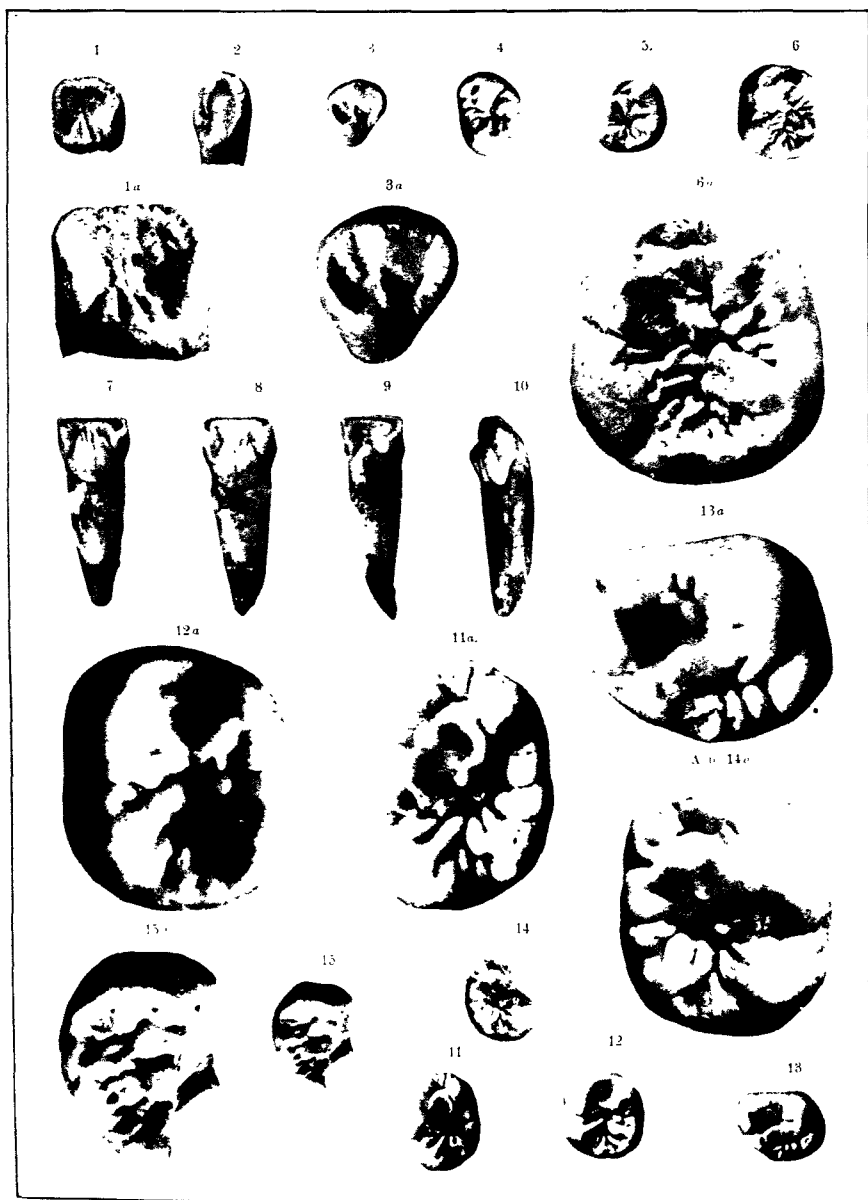
A NUMBER OF THE KRAPINA TEETH, MORE OR LESS ENLARGED.

1, permanent median upper incisor from a small child, 1a, the same greater enlargement; 2, permanent upper canine, 1 not more even fully developed, 3, permanent anterior lower premolar, right side, 3a, the same, greater enlargement 4, permanent second or upper molar 5, permanent lower left second molar, 6, permanent left lower first molar, 6a, the same, much enlarged; 7, permanent upper tooth; upper incisor, edge worn off 8, the same; 9, lateral upper permanent incisor; 10, the same 11, third permanent molar 11a, the same in greater enlargement, 12 the left lower permanent second molar 12a, the same much more enlarged 13, the right permanent second molar, 13a, the same in greater enlargement, 14, a third permanent molar, 14a, the same in greater enlargement 15, a permanent third molar, 15a, the same (From Gorjanović-Kramberger Mitth. Anthrop. Ges Wien XXXI.

Taking everything into consideration, it is evident that the diluvial man of Krapina represents a group belonging to the family of the *Homo neanderthalensis*. He is very ancient and in many respects anatomically primitive, though he also shows in various details an advancement toward the actual human form; and we can readily adopt Prof. Gorjanović-Kramberger's opinion that morphologically the Krapina man is not any special, collateral, and extinct branch of the genus *Homo*, but more probably a direct and not excessively far distant ancestor of the *Homo sapiens*.

THE PLEISTOCENE MAN OF JERSEY (ENGLAND).

In 1910 Messrs. Nicolle and Sinel, of the Island of Jersey, gave notice in *Man* and in a bulletin of the Jersey Society,[1] of the discovery in an old cave on the Island of Jersey of twelve highly interesting human teeth, belonging to a man of the Mousterian epoch. The principal details of the find, according to the clear account presented by the two authors and confirmed by the writer's observations on the spot, are as follows:

The cave where the ancient human remains were found is known as La Cotte, or La Cotte de St. Brelade, and is situated in a rough irregular cliff near the eastern horn of St. Brelade's Bay, Jersey. At this part of the island granite rocks, considerably weathered and broken, rise steeply to about 200 feet above mean tide level, the shore at their base being covered with accumulations of large, rounded, waterworn bowlders (pls. 29–31).

In one part of these cliffs there is an irregular rough ravine or gorge, about 40 feet in width, which penetrates inland about 150 feet. The side walls of this ravine are, in a large part, quite vertical, and in the base of these walls on the left, near the upper terminus of the gorge, is a large cave which bears the above name.

Before its exploration, the La Cotte cave was nearly filled by clay, bowlders, and blocks fallen from the much-weathered roof, and rubble drift in the form of a steeply sloping talus lay in front, obscuring a large portion of the mouth. Removal of this drift revealed the outline of the opening in the form of an irregular arch (pl. 31).

The first indication that the cave had once been utilized by man dates from 1881, when two local naturalists, while " geologizing " on that part of the coast, found a flint implement at the foot of the talus, and, tracing its source, came upon a slightly exposed section of the cave floor. There they found flint chippings, and one or two bones, apparently of a large bird, but no importance was attached to the discovery. About 1894, two members of the Société Jersiaise,

[1] Nicolle, E. T., and J. Sinel. Report on the exploration of the palaeolithic cave dwelling known as La Cotte, St. Brelade, Jersey. (Man. vol. 10, 1910, No. 102, pp. 185–188. Reprinted in 36e Bulletin de la Société Jersiaise, Jersey, p. 69.)

Mr. R. Colson and Dr. Chappuis, excavated a portion of the exposed floor section of the cave and found a considerable number of flint implements and besides that a quantity of bone breccia, which contained one tooth and one metatarsal of a variety of horse.

Subsequently various partial examinations of the accumulations in the cave resulted in the discovery of implements, and of a large number of flint chippings. All these are preserved in the Museum of the Société Jersiaise, at St. Helière.

In September, 1905, finally, the Jersey Society decided to explore the cave systematically, and Dr. Chappuis, Mr. Nicolle the secretary, and Mr. Colson, commenced work in that part of the exposed floor already mentioned. More flint implements were discovered, but at the commencement of October the work had to be abandoned owing to the rainy season and to the fact that the explorers were excavating under dangerous conditions. It then became clear that a considerable portion of the talus as well as some of the threatening rocks overhead had to be removed before the work could proceed.

Thus matters remained until July, 1910, when the society resolved to make another attempt at the exploration of the cave. With the help of experienced quarrymen excavation was commenced on August 1, and after a little over three weeks' work, sufficient of the rubble had been removed to reveal the form of the interior of the cave and to lay bare a portion of the floor about 11 feet square to the left of the entrance.

The dimensions of the cave as revealed at this stage were as follows: The entrance was 25 feet in height and about 20 feet in width. Just within, the roof sloped upward into a rough dome 30 to 32 feet from the floor. How far the cave entered the rock could not be ascertained, but judging from the slope of the roof downward towards the back, it was probably some 40 to 50 feet.

As soon as a portion of the floor had been reached a careful search and examination were commenced, with the following results:

The floor proper was not clearly marked, for layers of black soil, which proved to be a combination of ashes, carbonized wood and clay, were mixed up with whitish masses of bone detritus and clay compacted into breccia. Flint implements and chippings were interspersed plentifully throughout these deposits.

On the left of the entrance and at a distance from it of about 8 feet, was a hearth containing a quantity—probably a quarter of a ton or so—of wood ashes and carbonized wood. Close together, among the ashes of the hearth, were a few pebbles of granite and felsite bearing indications of having been heated.

The presence of bones was manifest all through the layers constituting the floor, but due to advanced decomposition of the material, the cave not being a dry one, only here and there could fragments

PLATE 29.
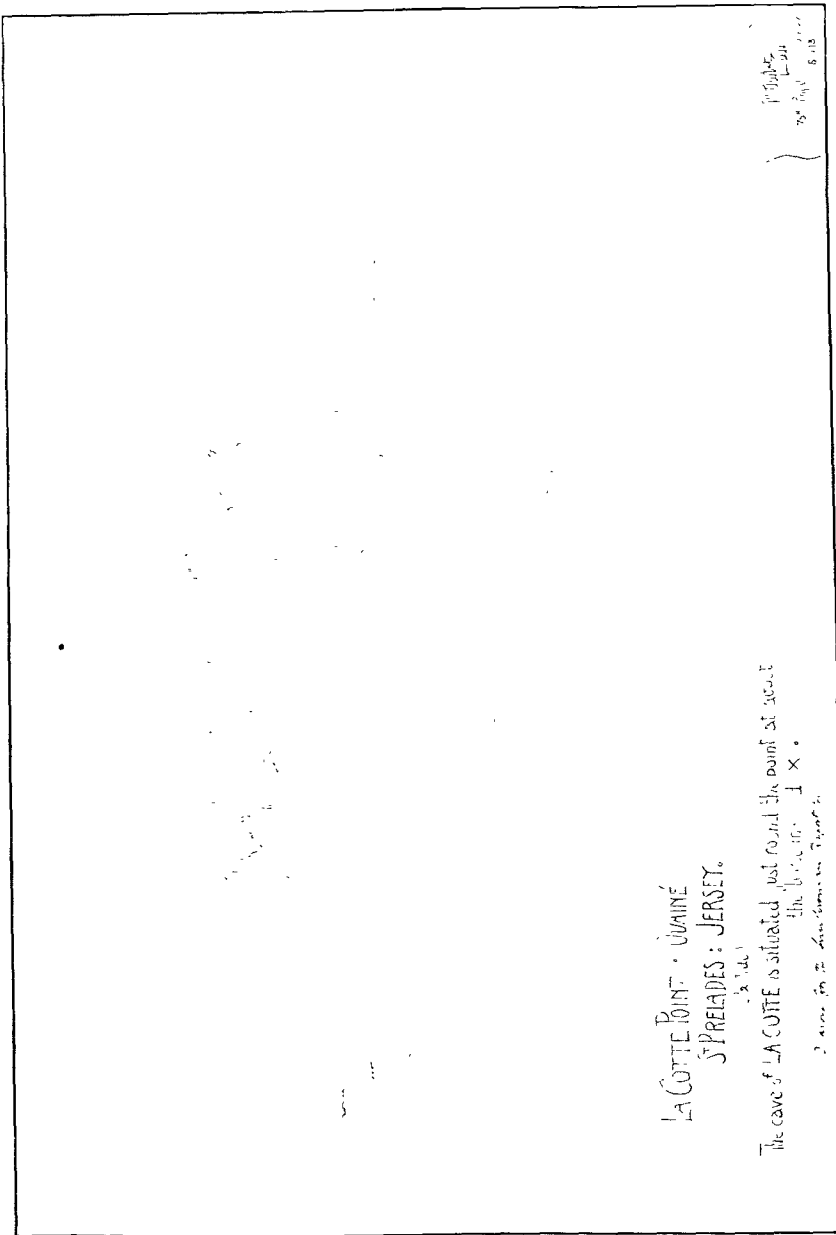
LA COTTE POINT · CUAINE
S: PRELADES: JERSEY.

The cave of LA COTTE is situated just round the point at about
the line of the 1 × .

A DISTANT VIEW OF THE ROCKY PROMONTORY IN WHICH IS LOCATED THE CAVE THAT YIELDED REMAINS OF THE "HOMO ERELADENSIS."

La Cotte Point showing the Cave
from a rock to the S.W.
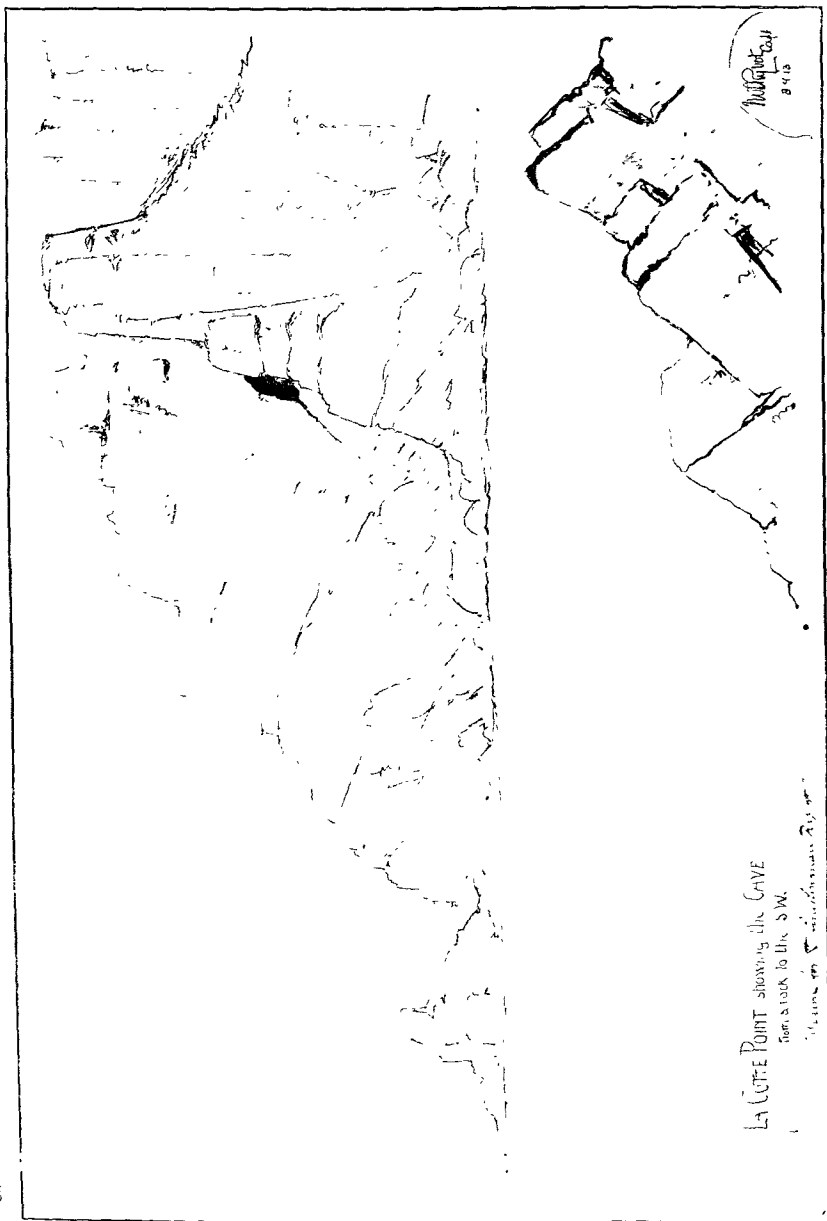
A View from Some Distance of the Cave at La Cotte, St. Brelade, Jersey, where Remains of the "Homo Breladensis" were Discovered.

retaining any form be obtained. Nevertheless, in one corner, at a slightly higher elevation than the earth, there was found a mass of bone from which some determinable portions could be secured; and a careful examination of this mass led to the most important result of the excavations to this time, namely, the discovery of nine human teeth. Three of these were from the upper, five from the lower jaw. They represent, as was later determined, teeth of both sides and of one individual, but unfortunately no trace of the once supporting bone was any more apparent.

All the bones and teeth recovered from the cave were taken to the British Museum for determination, and Drs. Woodward and Andrews identified the specimens as follows:

ANIMAL TEETH: Part of left lower premolar of the wooly rhinoceros, *Rhinoceros tichorhinus;* last premolar and first molar of reindeer, *Rangifer tarandus* (a large species apparently as large as the caribou); upper cheek teeth of a small species of *Horse;* parts of lower molars and upper cheek tooth of a large species of *Horse;* lower teeth in portion of jaw of one of small Bovidæ; and left incisor of *Bos,* Spec.?

NINE HUMAN TEETH, with subsequent recovery of four others.

BONES AND HORNS: Part of horn core of one of small Bovidæ; portion of antler of reindeer; bone, probably from articulation of foreleg of a deer; pelvic bones, probably from a small bovid; and a piece of bone, which fell to pieces on removal, from a rhinoceros.

Among the fragments that could not be definitely determined was apparently a portion of a human tibia.

Of flint instruments about 100 have been obtained. They are, without exception, of the well-known tongue-shaped Mousterian type, the " pointe a main " of Mortillet.

The cave gave no evidence of other than one occupation, and is thus probably free from the confusion which results when implements and remains of the fauna of different periods occur together and have become mixed by the work of burrowing animals, water during floods, and other agencies, as is often the case in similar deposits.

By their fauna and the uniform type of stone implements, the La Cotte cave deposits are shown clearly to be of the Mousterian epoch.

Further explorations of the site were carried on under the auspices of the Jersey Society in 1911 and again in 1912. They are reported by Nicolle and Sinel and by Marett.[1] They threw considerable light on the nature of the cave and its filling, and were extended to what

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[1] Nicolle, E. T., and Sinel. Report on the resumed exploration of " La Cotte," St. Brelade, by the Société Jersiaise, 1911. (Man, vol 12, 1912, No. 88, pp. 158–162. Also in 37ᵉ Bulletin de la Société Jersiaise, 1912, pp. 213–222.)

Marett, R. R. Pleistocene Man in Jersey. (Archæologia, vol. 62, Oxford, 1911, pp. 449–480.)

Marett, R. R. Further observations on prehistoric man in Jersey. (Archæologia, vol. 63, 1912, pp. 1–28.)

Marett, R. R., and G. F. B. De Gruchy. Excavation of a further portion of La Cotte de St. Brelade. (38ᵉ Bulletin de la Société Jersiaise, 1913, pp. 326–330.)

may prove to have been a part of the same hollow on the base of the wall of the opposite side of the gorge ("la Cotte de St. Brelade II"—Marett). They resulted in the discovery in both caves of numerous additional flint implements, all of the Mousterian type, and in the older excavation of more fragments of animal bones, referable principally to the wooly rhinoceros, the reindeer, a large variety of horse, and probably the *Bos primigenius*. But no further human bones or teeth came to notice.

Meanwhile the human teeth (pl. 32) were subjected to careful examination by Prof. Keith, of the Royal College of Surgeons, and Mr. Knowles, of the Oxford University. The results of these studies were published in 1911 in the Journal of Anatomy and Physiology,[1] and later, with some additions, in the thirty-seventh bulletin of the Jersey Society. The following embraces the gist of these reports, as well as of the writer's own observations.[2]

The teeth are in an unexpectedly good state of preservation, only the terminal parts of the roots being broken away. Their color is dark brown, with grayish white somewhat chalky looking crowns. All show an advanced degree of fossilization. The apices of the cusps were worn away in life and the finer architecture of the crown is as if faded, probably through corrosive action of the moisture in the deposits that enclosed the specimens.

Five of the teeth, namely a second left premolar, a first right and a second left molar, and the right and left third molar, with a part of the root of left incisor, belong to the upper jaw, while seven are from the lower jaw, being respectively a canine, first and second premolar with second molar of the left side, and a second incisor with second and third molars of the right side. All are probably from the same set and their characteristics are such that the ancient man they represent must be ranked anthropologically as one of the most primitive yet discovered.

The following illustration (pl. 33), shows a reconstruction of the upper and lower dental arches of the St. Brelade man, by Keith and Knowles, and the upper arch in the modern human skull, after Cunningham. It is seen at a glance that the Jersey teeth are larger than the modern in every direction and that in consequence the dental arches themselves must have been considerably larger.

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[1] Keith, A., and F. H. S. Knowles. A description of teeth of paleolithic man from Jersey. (Journ. Anat. Physiol., London, vol. 46, 1911, pp. 12–27. Reprinted, with an additional note, in 37ᵉ Bulletin de la Société Jersiaise, 1912, pp. 223–240. Abstract in Nature, vol. 86, 1911, pp. 415–416.)

[2] In June, 1912, the writer visited Jersey to examine the originals of these teeth and to visit the cave where they were discovered, and he wishes to warmly thank Mr. Sinel and Dr. Dunlap for the courteous treatment and facilities which they extended to him on this occasion, as well as Captain Rybot, of the 76 Punjabis, for his service in furnishing excellent sketches of the locality.

PLATE 31.

THE COTTE DE ST. BRELADE FROM NEAR.

(From a photograph furnished the Smithsonian Institution by Dr. R. R. Marett, of Oxford.

PLATE 32.
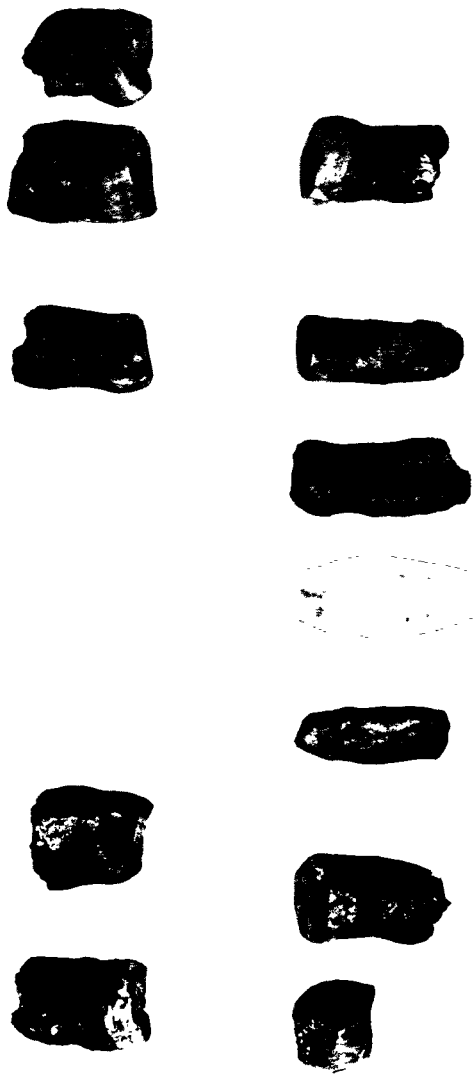
THE JERSEY TEETH

(From a photograph furnished to the Smithsonian Institution by Dr. R. R. Marett, of Oxford.)

PLATE 33.
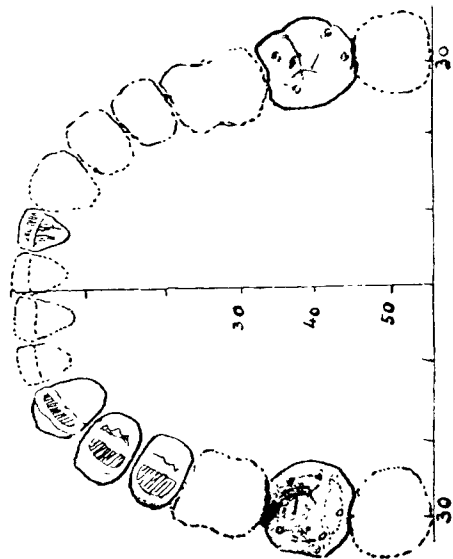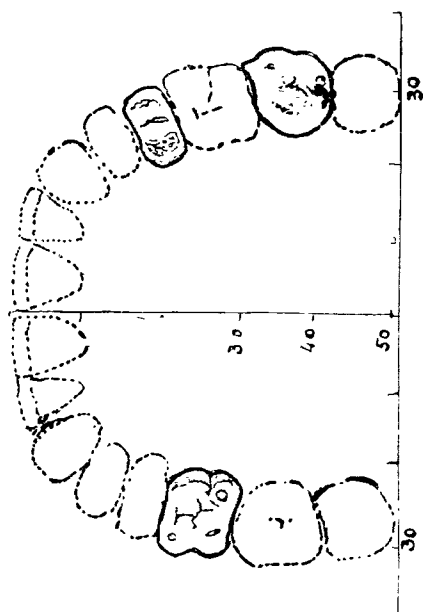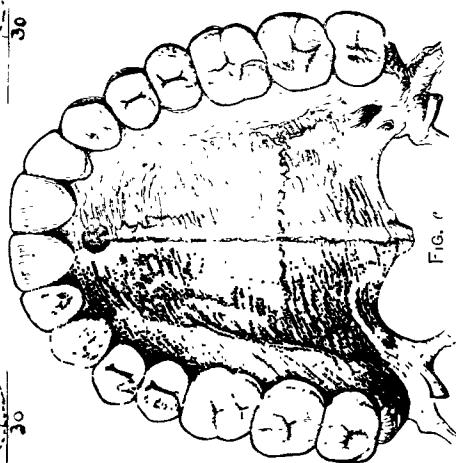
FIG. *a*.

FIG. *b*.

FIG. *c*.

FIG. *a*.—TEETH OF LOWER JAW OF THE JERSEY MAN, PLACED IN THEIR PROBABLE POSITIONS, WITH RECONSTRUCTION OF LOWER ALVEOLAR ARCH.   (AFTER KEITH.)
FIG. *b*.—TEETH OF THE UPPER JAW OF THE JERSEY MAN, IN THEIR PROBABLE POSITIONS, WITH RECONSTRUCTION OF THE UPPER ALVEOLAR ARCH   (AFTER KEITH.)
FIG. *c*.—MODERN UPPER DENTAL ARCH AND TEETH.   (AFTER CUNNINGHAM.)

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Another feature in which the Jersey teeth differ even more radically from the recent, is their extraordinarily stout roots. The diameters of the neck and roots of the Jersey teeth are almost equal to and in some cases exceed those of the crown, indicating that relatively great requirements were made on the teeth by the quality and possibly also quantity of the food. Such roots indicate unmistakably strong muscles of mastication and a stout massive lower jaw, probably somewhat smaller but scarcely less powerful than the still earlier Mauer mandible.

The roots of the Jersey premolars and molars are not only stout but they are also to a large extent fused. This is not an anthropoid feature, for in the higher apes these roots are well apart. The fusion is due to great development of the dentine and cement of the roots, brought about in this early man, in the opinion of Keith and Knowles, by a changed manner of mastication, characterized by more lateral besides vertical movements of the lower jaw. Other primitive features of the teeth are the early filling of the pulp cavities by deposits of dentine, thus providing an early adaptation for wear; the size and characters of the first premolars, which contrary to what occurs in present man are larger than the second bicuspids; and certain features of the canine as well as the molars.

Without going into more details, for which the reader will need to consult the originals—it may safely be concluded that the Jersey teeth constitute another valuable document of man's ancestry; and that they show an early man, probably an earlier representative of the *Homo neanderthalensis*, already quite advanced in denture from the prehuman forms, but still with teeth much more powerful as well as less specifically differentiated than those of present man.

The cave accumulations from which these teeth came are, fortunately, still far from exhausted which gives hopes of further important discoveries. The first cavern itself still presents a large accumulation of deposits that have not been explored, and, as mentioned above, there has been tapped a second cave in the rock opposite, while a communication between the two, as yet untouched, seems to lie behind the sagged-down rocks at the head of the ravine. The distant parts of these hollows in particular demands examination. The Société Jersiaise, under whose auspices the explorations of the site have hitherto progressed, will place the scientific world under especial obligation by carrying the work on with equal care to its conclusion.[1]

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[1] Since this was written, a grant has been secured from the British Association for the Advancement of Science, by Dr. R. R. Marett, for further exploration of the cave, and in a recent letter to the writer Dr. Marett intimates that the work under this grant was not fruitless.

THE FOSSIL MAN OF LA CHAPELLE-AUX-SAINTS.

One of the most interesting, best authenticated, and thanks to Prof. Marcellin Boule now best-known skeletons of Early Man, is that of " the fossil man of La Chapelle-Aux-Saints.

La Chapelle-Aux-Saints is a small village in the Departmer＋ of Corrèze, near the small railroad station of Vayrac and south of the town of Brive, in southern France. A little over 200 yards from the village and beyond the left bank of the small stream Sourdoire, in the side of a moderate elevation, is located a cave, now known as that of La Chapelle-Aux-Saints (pl. 34). In 1905 archeological exploration of this cave was undertaken by three Corrèze priests, the abbés A. and J. Bouyssonie and L. Bardon. These explorations which from the beginning were successful, resulting in the recovery of numerous industrial and other vestiges of paleolithic man, progressed gradually until the uniform archeological stratum was nearly exhausted, when, on the 3d of August, 1908, the excavators came across a shallow artificial fossa in the floor of the cave in which lay the bones of a remarkable human skeleton.

The human bones were carefully gathered and sent to Prof. Boule, of the Muséum d'Histoire Naturelle, in Paris, where they were cleaned and, as far as possible, restored; and the following December Prof. Boule demonstrated the skull, giving at the same time the first account of the find, before the Paris Academy of Sciences.[1] One week later Messrs. Bouyssonie and Bardon presented before the Academy their own observations, and these reports were followed at short intervals by several others before the same scientific body.[2]

Subsequently the skull and other parts of the skeleton were subjected by Prof. Boule to a thorough study and comparison, and the results of his work are published in a series of communications extending through the sixth, seventh and eighth volumes of the Annales de Paléontologie.[3]

The various reports show that the cave of La Chapelle-Aux-Saints is a moderate-sized and rather low cavity, about 6 meters (6.5 yards) long, 2 to 4 meters (2.2 to 4.4 yards) broad, and 1 to 1.50 meters (1.1 to 1.6 yards) high (fig. 9). When first approached it was seen to be nearly filled with accumulations, which later disclosed numerous traces of man, and by débris of the rock from the roof and sides. The deposits bearing traces of the presence of man were found to

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[1] Boule, M.   L'Homme fossile de La Chapelle-Aux-Saints.   (C. R. Acad. sc. 14 Dec., 1908; also L'Anthropologie vol. 19, 1908, pp. 513 and 519; vol. 20, 1909, p. 257; and vol. 22, 1911, p. 129.)

[2] Bouyssonie, A. J., and L. Bardon.   Découverte d'un squelette humain moustérien à la bouffia de La Chapelle-Aux-Saints.   (C. R. 21 Dec., 1908.)   Boule, M.   Sur la capacité cranienne des Hommes fossiles du type dit de Neanderthal.   (C. R. 17 May, 1909.) La squelette du tronc et des membres de l'Homme fossile de La Chapelle-Aux-Saints. (C. R. 7 June, 1909.)

[3] Paris, 1911 to 1913.   Also published as a separate volume.

PLATE 34.

THE LA CHAPELLE-AUX-SAINTS CAVE.

(After Boule.)

THE LA CHAPELLE-AUX-SAINTS SKULL. SIDE VIEW.
After Boule.

proceed from but one age and one culture, namely the Mousterian. The objects of archeological interest recovered during the excavation comprise in the main worked stones of the well-known Mousterian types, and remains of bones of fossil animals, such as the reindeer, bison, *Rhinoceros tichorhinus*, etc. The animal remains indicate that the deposits date from somewhere near the middle of the glacial epoch.

Under the accumulations the floor of the cavern was found to be whitish, hard, marly calcareous; and in this hard base, at the distance of a little over four meters from the entrance of the cave, was located the nearly rectangular, moderate-sized cavity [1] which lodged the fossil human skeleton. The depression was clearly made by the
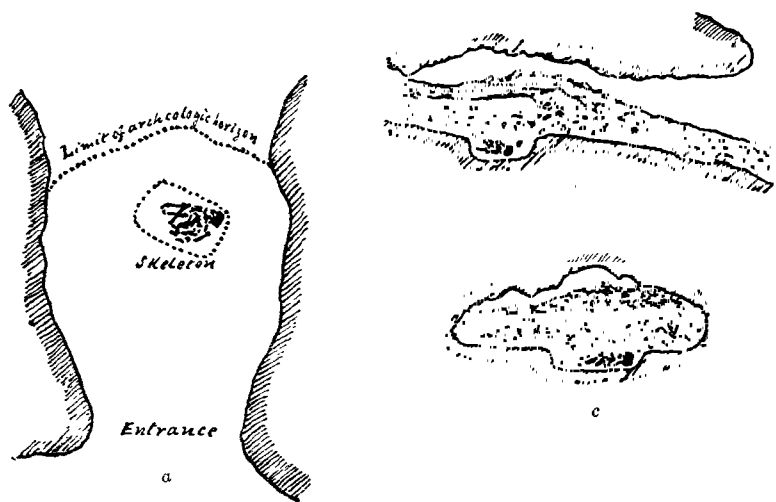
Fig. 9.—Cave of La Chapelle-aux-Saints. (After Bouyssonie & Bardon, and Boule.)
a, Floor; b, longitudinal section; c, transverse sections.

primitive inhabitants or visitors of the cave for the body and the whole represents very plainly a regular burial, the most ancient intentional burial thus far discovered.

The body lay on its back, with the head to the westward, the latter being surrounded by stones. The left arm was extended, the right probably bent so that the hand was applied to or lay near the head. The lower limbs were partly flexed. Above the head were found three or four large flat fragments of long bones of animals, and somewhat higher there lay, still in their natural relation, some foot bones of a large Bovid, suggesting that the whole foot of the animal may have been placed in that position. About the body were many

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[1] 1.45 meters long, 1 m. broad, and 30 cm. deep.

flakes of quartz and flint, some fragments of ochre, broken animal bones, etc., much as in the rest of the archeological stratum above the skeleton.

There was no indication that the deposits in the cave have been moved in any way since the burial of the human body. To the right of the fossa containing the skeleton there was an abundance of large fragments of various animal bones, of jaws and vertebræ of the reindeer, and vertebræ of a large Bovid, with some well-made implements of flint. The last-named vertebræ and the flint implements were covered by two large blocks of stone; and above these stones, at the side wall of the cave, the earth showed the effects of fire, but it was not possible to determine whether this was of the same date as the deposits or the human burial beneath.

Notwithstanding the care taken in the excavation some parts of the human skeleton were lost. What remains comprises the skull, almost complete, with the lower jaw; 21 vertebræ or pieces of same; 20 ribs or their fragments; an incomplete left clavicle; the two humeri, almost complete; the two radii and the two ulnæ, all more or less defective; a few bones of the hands and feet; portions of the pelvic bones, fragments of the right femur (from which it is possible to reconstruct the bone) and the lower half of the left femur; the two patellæ, and parts of the tibiæ.

The state of preservation of the specimens is exactly like that of the animal bones recovered from the deposits above the burial fossa. They are ferruginous in color, heavier than any corresponding recent human bones and very perceptibly mineralized.

Due to the kindness of Prof. Boule the writer was enabled in 1912 to see the originals of the Chapelle-aux-Saints skeleton. At that time, however, Prof. Boule's investigations on the specimens were not yet completed, in consequence of which it was not possible to undertake any detailed study on the bones, but even a brief examination was sufficient to impress one deeply, particularly in the case of the skull, with the great scientific value of the remains. They represent unquestionably another precious addition to the rapidly augmenting material evidence of the highly interesting type of ancient man, the *Homo neanderthalensis.*

Since the writer's visit to the Paris Museum, Prof. Boule's reports on the La Chapelle skeleton have been published in full. With these well-illustrated reports as well as a plaster model of the skull, and with what it was feasible to observe on the originals, it is possible to give the following brief notes on these specimens.

The La Chapelle skull, notwithstanding its many peculiarities, is plainly a normal specimen, not affected (except in the dental arches) by any disease or by any premature closure of sutures (pls. 35, 36).

PLATE 36.

THE SKULL OF LA CHAPELLE-AUX-SAINTS IN FRONT AND TOP VIEWS

(After Boule.)

PLATE 37.

La Chapelle ——
Neanderthal ----

Spy 1 ——
Spy 2 ----
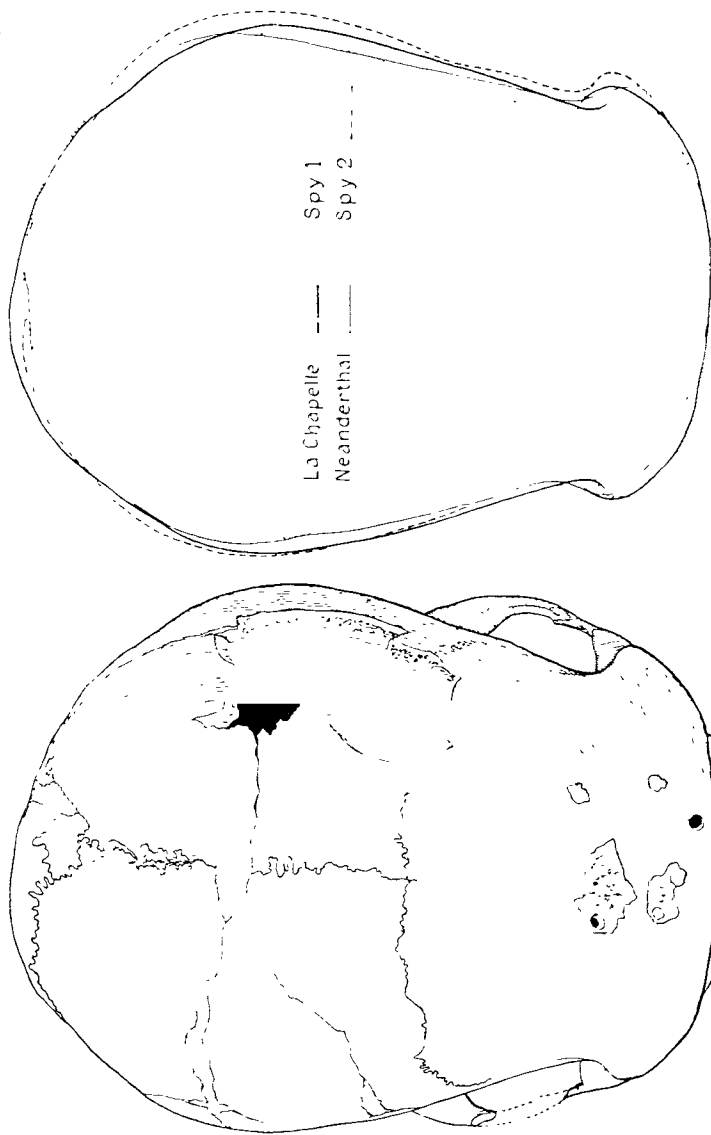
a. THE SKULL OF LA CHAPELLE-AUX-SAINTS, IN VERTICAL
PLANE.
(After Boule.)

b. OUTLINE OF THE VERTICAL PLANE IN THE LA CHAPELLE
AND OTHER SKULLS OF THE NEANDERTHAL TYPE.
(After Boule.)

The skull is distinctly masculine, and proceeds from an adult of somewhat advanced age.

Its vault is remarkably like that of the Neanderthal cranium, though somewhat larger. There is the same huge, prominent, complete supraorbital arch. The nasal process is equally broad and sloping considerably downward and backward. Due to the pronounced supraorbital arch the upper half of the orbits, as in the Neanderthal skull, has a somewhat forward and downward inclination, wholly unlike that of any man of to-day. The forehead, while low, is somewhat better formed than in the Neanderthal and Spy No. I crania and less sloping. The sagittal region is smooth and oval from side to side. The occiput is broad and shows a fair protrusion but as general in the Neanderthal type of skulls and in harmony with the rest of the vault, it is decidedly low. The outline of the vault when viewed from above is a prolonged ovoid, mildly asymetric in its posterior portion, due to a slightly greater size and protrusion backward of the right side (pl. 37). The mastoids are remarkably moderate for a male skull and one of this size, approaching in this respect the earlier primate form. The zygomae are stout and widely expanded, due to powerful temporal muscles.

The bones of the vault, again, as in the Neanderthal and other crania of this type, are thicker than in the skulls of modern man; nevertheless the capacity of the skull was quite large. Prof. Boule estimates it at from 1,600 to 1,620 c. c. This indicates not necessarily a superior brain, but rather one subserving to largely developed organs and powerful musculature.

Turning to the base of the skull, we find that while the glenoid fossæ, excepting their large size and one or two other peculiarities, are more like those of recent man than those for instance in the Krapina crania, the foramen magnum is of a very large size[1] and is situated, or rather extends farther backward than in man of the present day. There were probably other primitive features of the base, which the damaged parts do not allow to determine with certainty (figs. 10, 11).

The facial parts show malar bones with powerful frontal and zygomatic processes, but rather small and not prominent body. The nasal structures indicate that the nose was quite long and very broad; but the lower borders of the nasal aperture are already fairly sharp, as in more modern crania, and the nasal spine, though bifid, was well developed.

The orbits are not excessively high, but are spacious and deep. The suborbital (canine) fossæ are totally absent, the maxilla showing

[1] Corresponding to a stout spinal cord, which is generally associated with a pronounced development of the motor system and other parts of the body.

in their place even a slight convexity. The lower part of the face was prognathic, though evidently not excessively so. The dental arches regrettably show extensive effects of a suppurative process, as the result of which all but one or two of the teeth in the two jaws have been lost, and the height of the alveolar processes was much reduced by absorption. All that can be determined is that the sub-nasal portion of the upper jaw was quite high, and that the palate was enormous.

FIG. 10.—SKULL OF THE FOSSIL MAN OF LA CHAPELLE-AUX-SAINTS, AFTER RESTORATION OF THE NASAL BONES AND JAWS. (After Boule; reproduced by MacCurdy, Smithsonian Report for 1909.)

The lower jaw is large, stout, chinless—though not sloping backward at the symphisis, and otherwise primitive. It was doubtless high, but the reduction of the alveolar process through pyorrhœa and absorption does not permit a definite appreciation of this character.

Although only two badly worn premolars remain in the two jaws, it can nevertheless be clearly seen from the size of their roots, from the alveoli and from the size of the dental arches, that the teeth in this skull must have been very large.

The long and other bones of the skeleton are, on the whole, less remarkable than those of the Neanderthal or Spy remains, but the peculiarities and primitive features which they possess are of much the same order. The stature of the Chapelle-aux-Saints man is estimated by Prof. Boule to have been about 1.611 meters (5 ft. 3 in.), which is close to that of the Neanderthal man and the man of Spy. The bones are robust; the extremities of the long bones are large. The radii and ulnæ and especially the tibiæ and fibulæ, are again, as in other skeletons of the Neanderthal type, relatively short. There

Fig. 11.—Profiles of the cranium of a Chimpanzee, the cranium of La Chapelle-aux-Saints, and that of a modern Frenchman superposed, and with a common basi-nasal line equal in length for each. (After Boule; reproduced by MacCurdy, Smithsonian Report for 1909.)

Ba., Basion; Na., Nasion.

is also the pronounced curvature to the radius; and there are other peculiarities about the specimens an enumeration of which in this place is not feasible. Certain of these peculiarities indicate, according to Prof. Boule, that the individual from whom the Chapelle-aux-Saints skeletal remains proceed had, in common with others of the Neanderthal type, not as yet reached a fully erect posture.

The study of the brain of this individual, so far as possible from a cast of the cranial cavity, also shows various features of importance.[1]

[1] Boule, M., and R. Anthony. L'encéphale de l'homme fossile de La Chapelle-aux-Saints. (L'Anthropologie, vol. 22, 1911, pp. 129–196.)

Among the more strictly human characteristics are its large size, normally always a very favorable feature, though not necessarily an index of high intelligence; a predominance in size of the left over the right hemisphere; and certain other anatomical features. The more simian characteristics included especially the general form of the organ, the evident simplicity and coarseness of the convolutions, and the relatively poor development of the frontal parts, which is more pointed forward than obtains in man of to-day. "The brain, on the whole," to quote Prof. Boule, "is already human by the abundance of the cerebral substance; but this substance is still lacking the advanced organization which characterizes the brain of the actual man."

Regrettably, the La Chapelle-aux-Saints cave has now been completely exhausted, so that no hope can be entertained of securing further specimens from this particular spot; but the site lies in a region which is under careful scientific observation and other important discoveries in the neighborhood may yet be possible.

THE "LA QUINA" SKELETON.

On the 16th of October, 1911, Dr. Henri Martin, a physician and archeologist of Paris, reported before the Académie des Sciences of Paris the find of a very remarkable ancient human skeleton, at La Quina, Department of Charente, in France.[1] "We have discovered," he says, "on the 18th of September, at La Quina, a human skeleton of the Neanderthal type." It lay in a horizontal position, in clayey sand, at the distance of 4.5 meters from the base of a cliff. The deposits in which it rested represent the ancient muddy bed of the near-by stream Voultron, and belong, archæologically, to the lower Mousterian epoch. The clayey sand was covered by débris from the cliff portion, which in former times extended shelf like over the stream.

The skeleton lay 80 cm. (2.6 ft.) deep in the sand, and was not surrounded by any objects which would indicate an intentional burial. Its location and position seemed to show that the body was deposited where it lay accidentally. The clayey sand contained a few disseminated worked stones and a few bones that have been utilized by man, but showed none of the handsome pieces which characterized the superior Mousterian epoch. The age of the skeleton is, in all probability, referable to the earliest part of the middle Quaternary.

The remains have suffered from prolonged submersion and pressure, as a result of which the cranial bones were disjointed and in part broken; but from the first instant it could readily be seen that

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[1] Martin, Henri. Sur un squelette humain de l'époque moustérienne trouvé en Charente. (Comptes Rendus, tome 153, 1911, p. 728.)
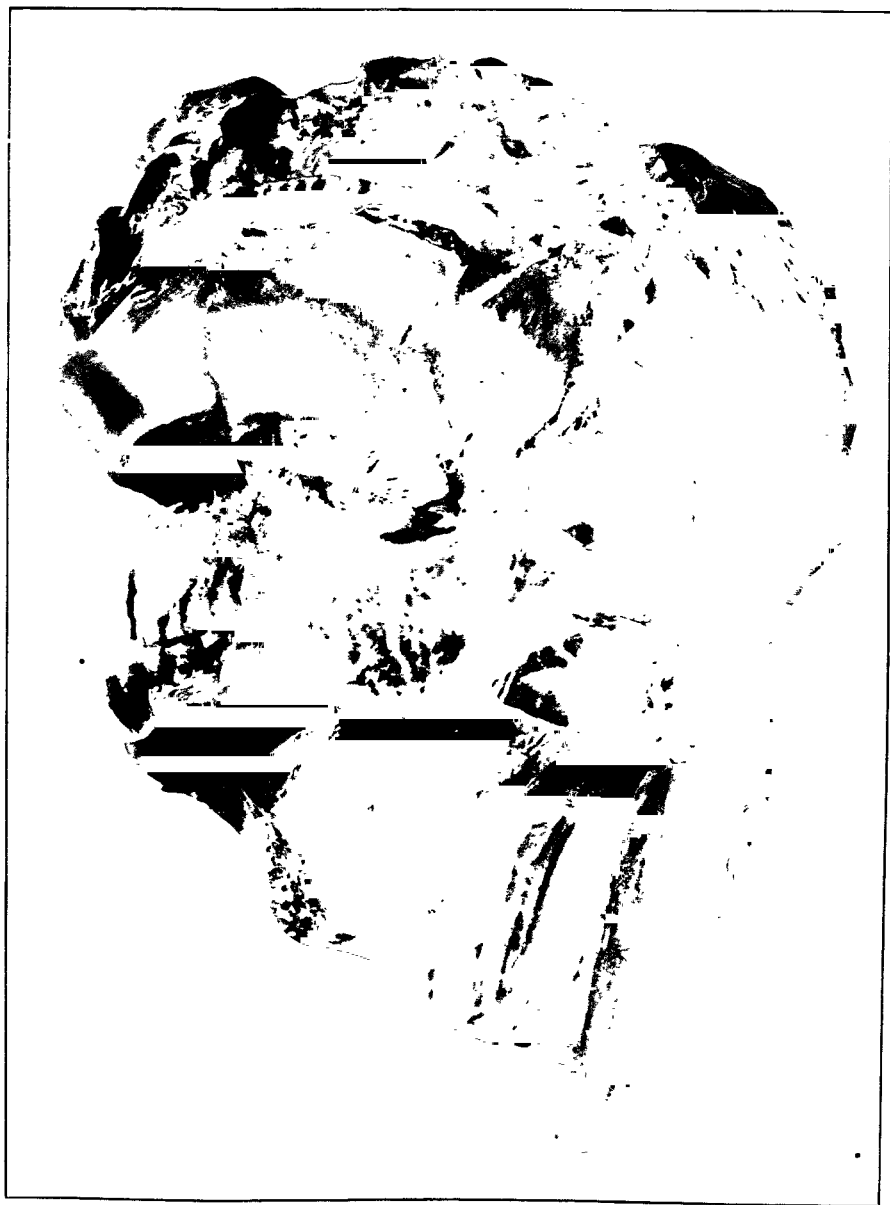
THE LA QUINA SKULL AND PARTS OF THE SKELETON STILL IN THE MATRIX.

After H. Martin.

PLATE 39.

THE LA QUINA SKULL, PARTLY RECONSTRUCTED.

(After H. Martin.)

the cranium presented in a high degree certain primitive character-istics in which it approaches those of the Neanderthal type.

A little later in the year Dr. Martin made a somewhat more exten-sive report on the find before the Prehistoric Society of France,[1] and in 1912 he published four other accounts relating to the dis-covery.[2] From these publications it appears that archeological ex-plorations at La Quina by Dr. Martin and others had been carried on intermittently for seven years before the human skeleton came to light, yielding many examples of paleolithic stone industries refer-able in the main to the upper or younger division of the Mousterian epoch. In addition a number of human teeth and various fragments of human bones, belonging to the upper Mousterian, were encountered during this time, but none, barring perhaps a larger portion of one lower jaw, are of special importance.[3]

The sandy layer which contained the La Quina skeleton yielded some worked stones representing lance points, knives, and scrapers, but all of inferior workmanship. Evidence was also found in traces of fire and calcined bones, that man of the period represented by the skeleton lived or took refuge in the caverns or holes of the cliff above. The animals on which the La Quina man lived were the reindeer, bison, horse, and rarely also the mammoth. The total Mousterian deposits at La Quina indicate a long duration of the epoch, and one during which man advanced considerably in the way of manufacture of his stone utensils.

The bones of the skeleton were taken to Paris, partly still in the sediments with which they were surrounded, and were then most carefully worked out from the matrix (pl. 38). The different parts of the skull, it was found, besides being disjointed, were forced to-gether so as to overlap, while the facial parts were broken and to a large extent deficient. With what was left of the jaws were 14 of the teeth.

The remains were seen at first sight to present a number of impor-tant primitive characteristics. The frontal bone showed a very pro-nounced supraorbital arch, with low and sloping forehead; the vault, it could readily be determined, had been low; the temporal fossæ were spacious, for the accommodation of powerful temporal muscles;

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[1] Martin, Henri. Presentation d'un crâne humain trouvé avec le squelette a la base du Moustérien de La Quina (Charente). (Bulletin de la Société Préhistorique Française, Séance du 26 Oct., 1911, pp. 1–12, 3 pls.)

[2] A propos de la découverte de l'homme fossile de La Quina. (Annales de la Faculté des Lettres de Bordeaux, etc., 4th series, vol. 14, 1912, pp. 61–64.) Le Crâne de l'homme fossile Moustérien de La Quina. (C. R. A. F. A. S., 1912, pp. 537–538.) L'homme fossile Moustérien de La Quina (Bull. Soc. Préhistorique Française, 1912, pp. 1–36, 4 pls.), and Position stratigraphique des Ossements humains recueillis dans le Moustérien de La Quina de 1908 à 1912. (Bull. Soc. Préhist. Française, 1912, pp. 1–8, 1 pl.)

[3] Pictured in the publication last named in footnote 2.

the jaws, particularly the mandible, were heavy; and the teeth were large in size, besides showing other remarkable features.

In June, 1912, Dr. Martin kindly showed the precious originals to the writer. At that time the skull was already fairly well restored, and impressed one as a typical, though not very massive, representative of the Neanderthal type of crania (pl. 39). It presents the same extraordinary supraorbital arch, a similar low forehead, similarly low vault, and similar ovoid outline when looked at from above, as the Neanderthal, Spy, Gibraltar, and other skulls of the group; but the occiput is rather more protruding. The lower jaw is stout and evidently possessed little, if any, chin prominence; the teeth, though considerably worn off, are very large. There is nothing pathological about the specimen or other parts of the skeleton. The individual from whom it proceeds was an adult of perhaps 45 years of age, and, in the opinion of Dr. Martin, supported by the relative gracility of the bones, it was a female. The skull, as well as the other bones, show advanced state of mineralization. The color of the skull is ocher to brownish yellow, with areas or ramifications of darker brown. As to the teeth, the dentine parts are darkened, but the enamel is well preserved and white. The other bones of the skeleton are yellowish gray.

The long and other bones, so far as saved, indicate an individual of moderate stature and good, but not excessive, musculature. As to the detailed characteristics of the bones as well those of the skull, it will be necessary to await the complete report by Dr. Martin.

An ingenious effort at a reconstruction of the head and neck of the La Quina woman by Dr. Martin will be found in the Bulletin de la Société Préhistorique Française. of 1913.[1]

THE MOUSTIER MAN.

Still another highly interesting and scientifically valuable skeleton of early man, recently discovered, is that of the so-called "*Homo mousteriensis* Hauseri." The skeleton is preserved in the Museum für Völkerkunde at Berlin, where it was seen by the writer. It was discovered in March 1908, by O. Hauser, during archeological excavation in what is known as "the lower Moustier cave," or "paleolithic station number 44," at Le Moustier, in the valley of the Vezère, Department of Dordogne, France, and was eventually purchased from Herr Hauser for the Berlin Museum.

The cave in question (fig. 12), or more properly rock shelter, when excavated gave numerous evidences of man's occupation, but no human bones. The skeleton under consideration was discovered in the terrace in front of the cave, almost vertically below its entrance. It

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[1] Séance du 27 Février, 1913.

PLATE 40.

HOMO MOUSTERIENSIS, FROM THE CAVERN OF LE MOUSTIER (DORDOGNE).

(After MacCurdy, from the Smithsonian Report for 1909.)

PLATE 41.

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THE SKULL OF HOMO MOUSTERIENSIS HOUSERI. SIDE VIEW.

lay about 3 feet deep and no disturbance in the superimposed deposits was noticeable.

The human bones were uncovered with great care in the presence of responsible witnesses, then covered again with earth and left in situ for several months, though shown during this time to a number of visitors. In August they were exposed for Virchow, v. d. Steinen, Klaatsch, and other scientific men, and finally, two days afterwards, in the presence of Prof. Klaatsch, they were gathered from the deposits.

A somewhat picturesque account of the discovery by Hauser will be found in the 1909 volume of the Archiv für Anthropologie.[1] The skeleton, it appears, lay on its side in a natural position, with the
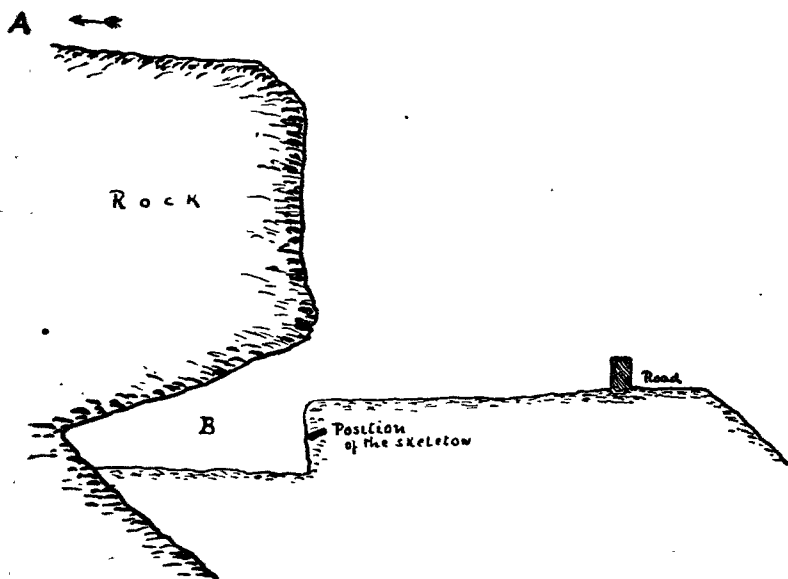
FIG. 12.—THE UPPER (A) AND LOWER (B) LE MOUSTIER CAVES AND THE POSITION OF THE SKELETON OF HOMO MOUSTERIENSIS. (After Klaatsch & Hauser.)

right hand under the occiput, the left extended along the body. About the body and among the bones were found seventy-four worked flints, ten of which were of a well-defined form. On the skull rested a charred bone of a *Bos primigenius*, and in the neighborhood of the thorax lay a tooth of the same animal. Besides this, 45 other fragments of animal bones were gathered in a close vicinity to the human remains.

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[1] Klaatsch, A., and O. Hauser. Homo mousteriensis Hauseri. Ein altdiluvialer Skelett-fund im Departement Dordogne und seine Zugehörigkeit zum Neandertaltypus. (Archiv f. Anthropologie, N. F., vol. 7, 1909.)

The examination of the human bones was begun on the spot by Prof. Klaatsch, who eventually reached the following conclusions:

The skeleton belongs to an adolescent of perhaps 16 years of age and probably of the male sex. The height of the boy, as estimated from the long bones, was probably 1.45 to 1.50 meters (4 feet 9 inches to 4 feet 11 inches).

The skull (pls. 40, 41) notwithstanding the youth of the subject, shows a number of characteristics which are peculiar to the Neanderthal group. While of a good size, with only moderately thick bones of the vault and the latter of a fair height, it shows nevertheless a rather low and sloping forehead; a well-marked complete supraorbital arch or torus, which later in life would doubtless have become much more prominent; relatively large dental arches, with large and in a number of particulars primitive teeth; a massive lower jaw with complete absence of the chin eminence; and other interesting features. The glenoid fossæ, especially that on the right, show an inclination upward and outward, as in the skulls of Krapina and as in the skulls of children in modern man. And there are a number of other characteristics on the Moustier skull and skeleton which connect the latter morphologically quite closely with the man of Krapina.

The long and other bones, so far as preserved, possess also numerous primitive characteristics. Especially noticeable among these are the relatively large extremities, particularly the head of the femur; a strong development of the external condyle of the thigh bones; the peculiar curvature of the same; the very marked curvature of the radius, etc. Klaatsch reached the deduction that the skeleton belongs undoubtedly to the *Homo neanderthalensis* variety of the early European.

OTHER SKELETAL REMAINS OF ANCIENT MAN IN EUROPE.

In addition to the more important skeletal remains of early man dealt with in the preceding pages, there exist a considerable number of specimens which, because of their isolated or defective nature, are of less value to science, or which have not as yet been properly studied and determined, or which, finally, retain some elements of uncertainty as to their true position in human chronology. And besides these there is a large additional series of skeletal remains, including the latest paleolithic and the neolithic remains, which, while still ancient, are nevertheless relatively near to man of the present date.

Among the earlier isolated or defective specimens may be mentioned first of all the two teeth of Taubach. One of these, a molar of the first dentition, was found in the old Quaternary deposits at

Taubach near Weimar, Germany, in 1892, by A. Weiss. The crown of this tooth shows considerable wear and this, with other characteristics of the specimen, created at first an impression that the tooth was perhaps not human. Later, however, the tooth was accepted as proceeding from a human child. Meanwhile one of the laborers at Taubach discovered in equally old deposits a first permanent left lower molar about the human nature of which there can be no question, and this tooth also shows various primitive features. Both these finds have been reported upon and the specimens described by Nehring.[1] The permanent molar is preserved in the museum in Jena.

Other specimens belonging to this category are the more or less defective lower jaws of La Naulette, Malarnaud, and Šipka. The La Naulette jaw was found in 1866 by Dupont in a cave at La Naulette, Belgium, together with an ulna and a few other fragments of human bones. The find was reported and the bones described by Dupont in the Bulletin de l'Académie Royale Belge, second series, volume 12, 1866, and by Topinard in the Révue d'Anthropologie of the same year. The original specimen is preserved in the Musée Royal d'Histoire Naturelle, Brussels. It is evidently a portion of the lower jaw of a subadult female. It lacks all chin prominence and shows primitive features of the alveoli and hence teeth, such as a broad root of the canine with the central groove on each side, and the very perceptibly increasing size of the sockets of the molars from before backwards.

The lower jaw of Malarnaud was discovered in 1889 in a small side chamber of the cave of Malarnaud, near the village of Montseron, Arize, France. It lay 2 meters (about 7 feet) deep beneath a layer of stalagmite, in a mass consisting of a great quantity of bones of Quaternary animals and reddish clay. The bone is that of an adolescent, the third molars being still in their sockets. The teeth are missing, with the exception of the first right molar. The jaw is not of great size and is rather low but stout. As the La Naulette specimen, it lacks the chin prominence such as characterizes the lower jaw of modern man.[2]

The Šipka specimen is a fragment of the lower jaw of a child, probably between the eighth and tenth year of age. It was found in 1880 in the Šipka cave, near Stramberk, Moravia, by Dr. Karel J. Maška, the deserving Moravian explorer. It shows six teeth—three incisors, the right canine, and the two right premolars, the

[1] Nehring, A. Über einen fossilen Menschenzahn aus dem Diluvium von Taubach bei Weimar. (Verh. Berl. G. Anthr., etc., Zeit. Ethn., 1895, pp. 338–340, 425–433.) Same author, Uber einen Menschlichen Molar aus dem Diluvium von Taubach bei Weimar. (Ibid., pp. 573–577.) See also Adloff, Das Gebiss des Menschen und der Anthropomorphen., Berlin, 1908; Schmidt, R. R., Die diluviale Vorzeit Deutschlands, Stuttgart, 1912; and Festschrift Anthropologische Versammlung Weimar, 1912.

[2] For original descriptions of the find, see Filhol, H.—Bull. de la Soc. Philomath. de Paris, 1889, and Congrès Anthrop. Préhist., 1889, p. 417.

three last named not yet erupted. The bone is very stout and shows
other primitive features, but the chin was already slightly developed.
The original of the Šipka jaw is still in the care of Prof. Maška at
Telč, Moravia, where it was seen by the writer.[1]

Among the specimens which while indubitably ancient have not
as yet been completely or finally described, should be mentioned, in
the first place the parts of the several skeletons discovered between
1909 and 1912 by Capitan and Peyrony, in the late Mousterian
archeological deposits of La Ferrassie, and the child's skull found by
the same explorers in 1909 in the cave of Pech de l'Aze, near Sarlat
(Dordogne), France. The writer has seen these specimens, which
are preserved and are being restored in the Museum d'Histoire Na-
turelle, Paris; they are in the care of Prof. Boule, who will eventu-
ally describe them. Certain observations on some parts of these
skeletons have already been included in Prof. Boule's reports on the
Chapelle-aux-Saints' skeleton. He holds that the remains belong to
the *Homo Neanderthalensis.*[2]

Among the ancient, but less definitely determined skeletal remains,
and among those belonging to the younger paleolithic (Late Quat-
ernary) period, there may be mentioned especially the Ochoz,[3]
Brux (Most),[4] Brno (Brünn) No. 1,[5] Canstadt,[4] Combe-Capelle,[6]
Eguisheim,[7] Galley Hill,[8] and possibly the Ipswich,[9] skulls and
skeletons. For the often not fully satisfactory details concerning
these specimens the reader must be referred to the original publi-
cations.

Of especial importance, however, is the magnificent collection of
ancient skeletal remains discovered at Předmost, Moravia, by Prof.
K. J. Maška. This splendid material, which consists of 14 human

[1] For detailed description of the Šipka and the jaw, with the earlier literature of
the find, see Maška, Karel, J.—Der diluviale Mensch in Mähren, 8°. Neutitschein, 1886.

[2] For first reports concerning these finds, see Boule, M.—Nouvelles entrées dans les
collections de Paléontologie du Muséum. (L'Anthropologie, vol. 22, 1911, pp. 112–113.)
Capitan, L., and Peyrony—Station préhistorique de la Ferrassie. (Revue anthropologique,
vol. 22, 1912, pp. 29–99.) Capitan, L. & Peyrony. Trois nouveaux squelettes humains
fossiles. (Revue anthropologique, Nov., 1912, pp. 439–440) ; and Obermaier, H.—Der
Mensch der Vorzeit, vol. 1, 1912. pp. 144–145, 339, 436.

[3] Rzehak, A. Verhandlungen des naturforschenden Vereins, Brünn, vol. 44, 1905 ; and
Zeitschrift des Mährischen Landesmuseums, vol. 9. Brünn, 1909, pp. 277–313.

[4] Schwalbe, G. Studien zur Vorgeschichte des Menschen. Zeitschrift für Morphologie
und Anthropologie, Sonderheft, 1906, with further biography.

[5] Makowsky, A. Der Mensch der Diluvialzeit Mährens. Brünn, 1899 ; Obermaier, H.—
Der Mensch der Vorzeit, 1912, pp. 298–352.

[6] "Homo Aurignacensis Hauseri" ; Klaatsch, H., and O. Hauser.—Prähist. Zeitschr.,
1910 ; and Klaatsch, H.—Die Aurignacrasse und ihre Stellung im Stammbaum der
Menschheit. (Zeitschr. Ethnol., 1910.)

[7] Broca, P. Fragments de crâne humaine d'Eguisheim. (Bull. Soc. D'Anthrop, Paris,
2d ser., Paris. 1867, pp. 129–131) : Schwalbe, G.—Der Schädel von Egisheim Beiträge
zur Anthropologie Elsass Lothringes Heft 3, Strassburg, 1902.

[8] Newton, E. T. Quarterly Journal of the Geological Society, August, 1895 ; also
Munro, R.—Paleolithic man, etc., Addenburg, 1912, pp. 109–115 ; Keith, A.—Ancient
types of man, 1911 ; also Duckworth. W. J. H.—Prehistoric man, Cambridge, 1912.

[9] Being determined and described by Prof. Arthur Keith.

skeletons, some of them almost complete, with additional skeletal parts from six other bodies, is now being studied by Prof. J. Matiegka, the director of the Anthropologický Ústav, of Prague. The writer has seen this collection on two occasions and he regards it as by far the most important assemblage of material from the transitional period between earlier and the latest paleolithic forms. It represents in a measure the much searched-for bridge between the Neanderthal and recent man. Archeologically, these valuable skeletons belong to the earlier Solutrean or the Aurignacean.

Besides the above described or enumerated specimens, there are many others scattered over the museums of Europe, for which great or less antiquity has been at some time, or is still being claimed. In many of these instances the student finds that the evidence adduced and the testimony of the skeletal parts themselves speak rather against any great age, or leave the subject in serious doubt. It would seem best for the progress of science to eliminate all such specimens, with perhaps some of those mentioned above, from consideration, unless or until new and ample evidence be found to convince us that they really deserve place in the range of the precious authentic documents that represent the earlier phases of man's natural history.

The gradually accumulating finds which throw light on the physical past of man, have naturally stimulated further exploration in the same lines; and the various failures and uncertainties connected with some of the finds in the past have impressed all investigators in the field with the necessity of the most careful and properly controlled procedure. Besides men of science, the educated public, engineers controlling public works, and even many among the workmen in Europe have been impressed by these remarkable discoveries, and in hundreds of instances are doubtless watching for new treasures. Under these conditions we are justified in hoping that from time to time we shall receive additions to the precious material already in our hands; that these additions will fill the existing vacua, and gradually extend farther back to the more strictly intermediary forms between man and his ancestral stock, and perhaps eventually even to the source of these link-forms themselves, to the peculiar morphologically unstable family of the anthropogenous primates.

While the anthropologist is thus painfully and slowly reconstructing the past physical history of man, he is also with every new fact adding another imperishable block to the foundation upon which will stand not only the knowledge of the future in regard to man himself, but also the laws of his further physical development, and radically even those of his beliefs and his moral behavior. This is a part of the service of anthropology to humanity.

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THE REDISTRIBUTION OF MANKIND.[1]

By Prof. H. N. DICKSON, M. A., D. Sc.

Since the last meeting of this section the tragic fate of Capt. Scott's party, after its successful journey to the South Pole, has become known; and our hopes of welcoming a great leader, after great achievement, have been disappointed. There is no need to repeat here the narrative of events or to dwell upon the lessons afforded by the skill and resource and heroic persistence which endured to the end. All these have been, or will be, placed upon permanent record. But it is right that we should add our word of appreciation and proffer our sympathy to those who have suffered loss. It is for us also to take note that this last of the great Antarctic expeditions has not merely reached the pole, as another has done, but has added, to an extent that few successful exploratory undertakings have ever been able to do, to the sum of scientific geographical knowledge. As the materials secured are worked out it will, I believe, become more and more apparent that few of the physical and biological sciences have not received contributions, and important contributions, of new facts, and also that problems concerning the distribution of the different groups of phenomena and their action and reaction upon one another—the problems which are specially within the domain of the geographer—have not merely been extended in their scope but have been helped toward their solution.

The reaching of the two poles of the earth brings to a close a long and brilliant chapter in the story of geographical exploration. There is still before us a vista of arduous research in geography, bewildering almost in its extent, in such a degree, indeed, that " the scope of geography " is in itself a subject of perennial interest., But the days of great pioneer discoveries in topography have definitely drawn to their close. We know the size and shape of the earth, at least to a first approximation, and as the map fills up we know that there can be no new continents and no new oceans to discover, although all are still, in a sense, to conquer. Looking back, we find that the qualities

of human enterprise and endurance have shown no change; we need no list of names to prove that they were alike in the days of the earliest explorations, of the discovery of the New World, or of the sea route to India, of the " Principall Navigations," or of this final attainment of the poles.   The love of adventure and the gifts of courage and endurance have remained the same; the order of discovery has been determined rather by the play of imagination upon accumulated knowledge, suggesting new methods and developing appropriate inventions.   Men have dared to do risky things with inadequate appliances, and in doing so have shown how the appliances may be improved and how new enterprises may become possible as well as old ones easier and safer.   As we come to the end of these " great explorations," and are restricted more and more to investigations of a less striking sort, it is well to remember that in geography, as in all other sciences, research continues to make as great demands as ever upon those same qualities and that the same recognition is due to those who continue in patient labor.

When we look into the future of geographical study it appears that for some time to come we shall still be largely dependent upon work similar to that of the pioneer type to which I have referred, the work of perfecting the geographer's principal weapon, the map.   There are many parts of the world about which we can say little except that we know they exist; even the topographical map, or the material for making it, is wanting; and of only a few regions are there really adequate distributional maps of any kind.   These matters have been brought before this section and discussed very fully in recent years, so I need say no more about them, except perhaps to express the hope and belief that the production of topographical maps of difficult regions may soon be greatly facilitated and accelerated with the help of the new art of flying.

I wish to-day rather to ask your attention for a short time to a phase of pioneer exploration which has excited an increasing amount of interest in recent years.   Civilized man is, or ought to be, beginning to realize that in reducing more and more of the available surface of the earth to what he considers a habitable condition he is making so much progress, and making it so rapidly, that the problem of finding suitable accommodations for his increasing numbers must become urgent in a few generations.   We are getting into the position of the merchant whose trade is constantly expanding and who foresees that his premises will shortly be too small for him.   In our case removal to more commodious premises elsewhere seems impossible—we are not likely to find a means of migrating to another planet—so we are driven to consider means of rebuilding on the old site and so making the best of what we have that our business may not suffer.

In the type of civilization with which we are most familiar there are two fundamental elements—supplies of food energy and supplies of mechanical energy. Since at present, partly because of geographical conditions, these do not necessarily (or even in general) occur together, there is a third essential factor, the line of transport. It may be of interest to glance, in the cursory manner which is possible upon such occasions, at some geographical points concerning each of these factors and to hazard some speculations as to the probable course of events in the future.

In his presidential address to the British Association at its meeting at Bristol in 1898, Sir William Crookes gave some valuable estimates of the world's supply of wheat, which, as he pointed out, is " the most sustaining food grain of the great Caucasian race." Founding upon these estimates, he made a forecast of the relations between the probable rates of increase of supply and demand, and concluded that " Should all the wheat-growing countries add to their [producing] area to the utmost capacity, on the most careful calculation the yield would give us only an addition of some 100,000,000 acres, supplying, at the average world yield of 12.7 bushels to the acre, 1,270,000,000 bushels, just enough to supply the increase of population among bread eaters till the year 1931." The president then added, " Thirty years is but a day in the life of a nation. Those present who may attend the meeting of the British Association 30 years hence will judge how far my forecasts are justified."

Half the allotted span has now elapsed, and it may be useful to inquire how things are going. Fortunately, this can be easily done, up to a certain point, at any rate, by reference to a paper published recently by Dr. J. F. Unstead,[1] in which comparisons are given for the decades 1881–1890, 1891–1900, and 1901–1910. Dr. Unstead shows that the total wheat harvest for the world may be estimated at 2,258,000,000 bushels for the first of these periods, 2,575,000,000 for the second, and 3,233,000,000 for the third, increases of 14 per cent and 25 per cent, respectively. He points out that the increases were due " mainly to an increased acreage," the areas being 192,000,000, 211,000,000, and 242,000,000 acres, but also " to some extent (about 8 per cent) to an increased average yield per acre, for while in the first two periods this was 12 bushels, in the third period it rose to 13 bushels per acre."

If we take the period 1891–1900, as nearly corresponding to Sir William Crookes's initial date, we find that the succeeding period shows an increase of 658,000,000 bushels, or about half the estimated increase required by 1931, and that attained chiefly by " increased acreage."

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[1] Geographical Journal, August and September, 1913.

But signs are not wanting that increase in this way will not go on indefinitely. We note (also from Dr. Unstead's paper) that in the two later periods the percentage of total wheat produced which was exported from the United States fell from 32 to 19, the yield per acre showing an increase meanwhile to 14 bushels. In the Russian Empire the percentage fell from 26 to 23, and only in the youngest of the new countries—Canada, Australia, and the Argentine—do we find large proportional increases. Again, it is significant that in the United Kingdom, which is, and always has been, the most sensitive of all wheat-producing countries to variations in the floating supply, the rate of falling off of home production shows marked if irregular diminution.

Looking at it in another way, we find (still from Dr. Unstead's figures) that the total amount sent out by the great exporting countries averaged in 1881–1890, 295,000,000 bushels; 1891–1900, 402,-000,000; 1901–1910, 532,000,000. These quantities represent, respectively, 13, 15.6, and 16.1 per cent of the total production, and it would appear that the percentage available for export from these regions is, for the time at least, approaching its limit—i. e., that only about one-sixth of the wheat produced is available from surpluses in the regions of production for making good deficiencies elsewhere.

There is, on the other hand, abundant evidence that improved agriculture is beginning to raise the yield per acre over a large part of the producing area. Between the periods 1881–1890 and 1901–1910 the average in the United States rose from 12 to 14 bushels; in Russia, from 8 to 10; in Australia, from 8 to 10. It is likely that in these last two cases at least a part of the increase is due merely to more active occupation of fresh lands as well as to the use of more suitable varieties of seed, and the effect of improvements in methods of cultivation alone is more apparent in the older countries. During the same period the average yield increased in the United Kingdom from 28 to 32 bushels, in France from 17 to 20, Holland, 27 to 33; Belgium, 30 to 35; and it is most marked in the German Empire, for which the figures are 19 and 29.

In another important paper [1] Dr. Unstead has shown that the production of wheat in North America may still in all likelihood be very largely increased by merely increasing the area under cultivation, and the reasoning by which he justifies this conclusion certainly holds good over large districts elsewhere. It is of course impossible, in the present crude state of our knowledge of our own plant, to form any accurate estimate of the area which may, by the use of suitable seeds or otherwise, become available for extensive cultivation. But I think it is clear that the available proportion of the total supply

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[1] Geographical Journal, April and May, 1912.

from "extensive" sources has reached, or almost reached, its maximum, and that we must depend more and more upon intensive farming, with its greater demands for labor.

The average total area under wheat is estimated by Dr. Unstead as 192,000,000 acres for 1881–1890, 211,000,000 acres for 1891–1900, and 242,000,000 acres for 1901–1910. Making the guess—for we can make nothing better—that this area may be increased to 300,000,000 acres, and that under ordinary agriculture the average yield may eventually be increased to 20 bushels over the whole, we get an average harvest of 6,000,000,000 bushels of wheat. The average wheat eater consumes, according to Sir William Crooke's figures, about 4½ bushels per annum; but the amount tends to increase. It is as much (according to Dr. Unstead) as 6 bushels in the United Kingdom and 8 bushels in France. Let us take the British figure, and it appears that on a liberal estimate the earth may in the end be able to feed permanently 1,000,000,000 wheat eaters. If prophecies based on population statistics are trustworthy, the crisis will be upon us before the end of this century. After that we must either depend upon some substitute to reduce the consumption per head of the staple foodstuff, or we must take to intensive farming of the most strenuous sort, absorbing enormous quantities of labor and introducing, sooner or later, serious difficulties connected with plant food. We leave the possibility of diminishing the rate of increase in the number of bread eaters out of account.

We gather, then, that the estimates formed in 1898 are in the main correct, and the wheat problem must become one of urgency at no distant date, although actual shortage of food is a long way off. What is of more immediate significance to the geographer is the element of change, of return to earlier conditions, which is emerging even at the present time. If we admit, as I think we must do, that the days of increase of extensive farming on new land are drawing to a close, then we admit that the assignment of special areas for the production of the food supply of other distant areas is also coming to its end. The opening up of such areas, in which a sparse population produces food in quantities largely in excess of its own needs, has been the characteristic of our time, but it must give place to a more uniform distribution of things, tending always to the condition of a moderately dense population, more uniformly distributed over large areas, capable of providing the increased labor necessary for the higher type of cultivation, and self-supporting in respect of grain food at least. We observe in passing that the colonial system of our time only became possible on the large scale with the invention of the steam locomotive, and that the introduction of railway systems in the appropriate regions, and the first tapping of nearly all such regions on the globe, has taken less than a century.

Concentration in special areas of settlement, formerly chiefly effected for military reasons, has in modern times been determined more and more by the distribution of supplies of energy. The position of the manufacturing district is primarily determined by the supply of coal. Other forms of energy are, no doubt, available, but, as Sir William Ramsay showed in his presidential address at the Portsmouth meeting in 1911, we must in all probability look to coal as being the chief permanent source.

In the early days of manufacturing industries the main difficulties arose from defective land transport. The first growth of the industrial system, therefore, took place where sea transport was relatively easy; raw material produced in a region near a coast was carried to a coal field also near a coast, just as in the times when military power was chiefly a matter of "natural defenses," the center of power and the food-producing colony had to be mutually accessible. Hence the Atlantic took the place of the Mediterranean, Great Britain eventually succeeded Rome, and eastern North America became the counterpart of Northern Africa. It is to this, perhaps more than to anything else, that we in Britain owe our tremendous start amongst the industrial nations, and we observe that we used it to provide less favored nations with the means of improving their system of land transport, as well as actually to manufacture imported raw material and redistribute the products.

. But there is, of course, this difference between the supply of foodstuff (or even military power) and mechanical energy, that in the case of coal at least it is necessary to live entirely upon capital; the storing up of energy in new coal fields goes on so slowly in comparison with our rate of expenditure that it may be altogether neglected. Now, in this country we began to use coal on a large scale a little more than a century ago. Our present yearly consumption is of the order of 300,000,000 tons, and it is computed [1] that at the present rate of increase "the whole of our available supply will be exhausted in 170 years." With regard to the rest of the world we can not, from lack of data, make even the broad assumptions that were possible in the case of wheat supply, and for that and other reasons it is therefore impossible even to guess at the time which must elapse before a universal dearth of coal becomes imminent; it is perhaps sufficient to observe that to the best of our knowledge and belief one of the world's largest groups of coal fields (our own) is not likely to last three centuries in all.

Here again the present interest lies rather in the phases of change which are actually with us. During the first stages of the manufacturing period energy in any form was exceedingly difficult to trans-

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[1] General Report of the Royal Commission on Coal Supplies, 1906.

port, and this led to intense concentration. Coal was taken from the most accessible coal field and used, as far as possible, on the spot. It was chiefly converted into mechanical energy by means of the steam engine, an extremely wasteful apparatus in small units, hence still further concentration; thus the steam engine is responsible in part for the factory system in its worst aspect. The less accessible coal fields were neglected. Also, the only other really available source of energy—water power—remained unused, because the difficulties in the way of utilizing movements of large quantities of water through small vertical distances (as in tidal movements) are enormous; the only easily applied source occurs where comparatively small quantities of water fall through considerable vertical distances, as in the case of waterfalls. But, arising from the geographical conditions, waterfalls (with rare exceptions, such as Niagara) occur in the " torrential " part of the typical river course, perhaps far from the sea, almost certainly in a region too broken in surface to allow of easy communication or even of industrial settlement of any kind.

However accessible a coal field may be to begin with, it sooner or later becomes inaccessible in another way, as the coal near the surface is exhausted and the workings get deeper. No doubt the evil day is postponed for a time by improvements in methods of mining—a sort of intensive cultivation—but as we can put nothing back the end must be the same, and successful competition with more remote but more superficial deposits becomes impossible. And every improvement in land transport favors the geographically less accessible coal fields.

From this point of view it is impossible to overestimate the importance of what is to all intents and purposes a new departure of the same order of magnitude as the discovery of the art of smelting iron with coal, or the invention of the steam engine, or of the steam locomotive. I mean the conversion of energy into electricity, and its transmission in that form (at small cost and with small loss) through great distances. First we have the immediately increased availability of the great sources of cheap power in waterfalls. The energy may be transmitted through comparatively small distances and converted into heat in the electric furnace, making it possible to smelt economically the most refractory ores, as those of aluminium, and converting such unlikely places as the coast of Norway or the West Highlands of Scotland into manufacturing districts. Or it may be transmitted through greater distances to regions producing quantities of raw materials, distributed there widespread to manufacturing centers, and reconverted into mechanical energy. The Plain of Lombardy produces raw material in abundance, but Italy has no coal supply. The waterfalls of the Alps yield much energy, and this transmitted in the form of electricity, in some cases for great distances, is converting

northern Italy into one of the world's great industrial regions. Chisholm gives an estimate of a possible supply of power amounting to 3,000,000 horsepower, and says that of this about one-tenth was already being utilized in the year 1900.

But assuming again, with Sir William Ramsay, that coal must continue to be the chief source of energy, it is clear that the question of accessibility now wears an entirely different aspect. It is not altogether beyond reason to imagine that the necessity for mining, as such, might entirely disappear, the coal being burnt in situ and energy converted directly into electricity. In this way some coal fields might conceivably be exhausted to their last pound without serious increase in the cost of getting. But for the present it is enough to note that, however inaccessible any coal field may be from supplies of raw material, it is only necessary to establish generating stations at the pit's mouth and transport the energy to where it can be used. One may imagine, for example, vast manufactures carried on in what are now the immense agricultural regions of China, worked by power supplied from the great coal deposits of Shansi.

There is, however, another peculiarity of electrical power which will exercise increasing influence upon the geographical distribution of industries. The small electric motor is a much more efficient apparatus than the small steam engine. We are, accordingly, already becoming familiar with the great factory in which, instead of all tools being huddled together to save loss through shafting and belting, and all kept running all the time, whether busy or not (because the main engine must be run), each tool stands by itself and is worked by its own motor, and that only when it is wanted. Another of the causes of concentration of manufacturing industry is therefore reduced in importance. We may expect to see the effects of this becoming more and more marked as time goes on, and other forces working toward uniform distribution make themselves more felt.

The points to be emphasized so far, then, are, first, that the time when the available areas whence food supply, as represented by wheat, is derived are likely to be taxed to their full capacity within a period of about the same length as that during which the modern colonial system has been developing in the past; secondly, that cheap supplies of energy may continue for a longer time, although eventually they must greatly diminish; and, thirdly, there must begin in the near future a great equalization in the distribution of population. This equalization must arise from a number of causes. More intensive cultivation will increase the amount of labor required in agriculture, and there will be less difference in the cost of production and yield due to differences of soil and climate. Manufacturing industries will be more uniformly distributed, because energy, obtained from a larger number of sources in the less accessible places, will be distrib-

uted over an increased number of centers. The distinction between agricultural and industrial regions will tend to become less and less clearly marked, and will eventually almost disappear in many parts of the world.

The effect of this upon the third element is of first-rate importance. It is clear that as the process of equalization goes on the relative amount of long-distance transport will diminish, for each district will tend more and more to produce its own supply of staple food and carry on its own principal manufactures. This result will naturally be most marked in what we may call the " east-and-west " transport, for as climatic controls primarily follow the parallels of latitude, the great quantitative trade, the flow of foodstuffs and manufactured articles to and fro between peoples of like habits and modes of life, runs primarily east and west. Thus the transcontinental functions of the great North American and Eurasian railways, the east-and-west systems of the inland waterways of the two continents, and the connecting links furnished by the great ocean ferries must become of relatively less importance.

The various stages may be represented, perhaps, in some such manner as this. If I is the cost of producing a thing locally at a place A by intensive cultivation or what corresponds to it, if E is the cost of producing the same thing at a distant place B, and T the cost of transporting it to A, then at A we may at some point of time have a more or less close approximation to

$$I = E + T.$$

We have seen that in this country, for example, I has been greater than $E + T$ for wheat ever since, say, the introduction of railways in North America, that the excess tends steadily to diminish, and that however much it may be possible to reduce T either by devising cheaper modes of transport or by shortening the distance through which wheat is transported, $E + T$ must become greater than I, and it will pay us to grow all or most of our own wheat. Conversely, in the seventies of last century I was greater than $E + T$ in North America and Germany for such things as steel rails and rolling stock, which we in this country were cultivating " extensively " at the time on more accessible coal fields, with more skilled labor and better organization than could be found elsewhere. In many cases the positions are now, as we know, reversed, but geographically I must win all round in the long run.

In the case of transport between points in different latitudes, the conditions are, of course, altogether dissimilar, for in this case commodities consist of foodstuffs, or raw materials, or manufactured articles, which may be termed luxuries, in the sense that their use is scarcely known until cheap transport makes them easily accessible,

when they rapidly become " necessaries of life." Of these the most familiar examples are tea, coffee, cocoa, and bananas, india rubber and manufactured cotton goods. There is here, of course, always the possibility that wheat as a staple might be replaced by a foodstuff produced in the tropics, and it would be extremely interesting to study the geographical consequences of such an event as one-half of the surface of the earth suddenly coming to help in feeding the two quarters on either side; but for many reasons, which I need not go into here, such a consummation is exceedingly unlikely. What seems more probable is that the trade between different latitudes will continue to be characterized specially by its variety, the variety doubtless increasing, and the quantity increasing in still larger measure. The chief modification in the future may perhaps be looked for in the occasional transference of manufactures of raw materials produced in the tropics to places within the tropics, especially when the manufactured article is itself largely consumed near regions of production. The necessary condition here is a region, such as, e. g., the monsoon region, in which there is sufficient variation in the seasons to make the native population laborious; for then, and apparently only then, is it possible to secure sufficient industry and skill by training, and therefore to be able to yield to the ever-growing pressure in more temperate latitudes due to increased cost of labor. The best examples of this to-day are probably the familiar ones of cotton and jute manufacture in India. With certain limitations, manufacturing trade of this kind is, however, likely to continue between temperate and strictly tropical regions, where the climate is so uniform throughout the year that the native has no incentive to work. There the collection of the raw material is as much as, or even more than can be looked for—as in the case of mahogany or wild rubber. Where raw material has to be cultivated—as cotton, cultivated rubber, etc.—the raw material has to be produced in regions more of the monsoon type, but it will probably—perhaps as much for economic as geographical reasons—be manufactured at some center in the temperate zones, and the finished product transported thence, when necessary, to the point of consumption in the tropics.

We are here, however, specially liable to grave disturbances of distribution arising from invention of new machinery or new chemical methods; one need only mention the production of sugar or indigo. Another aspect of this which is not without importance may perhaps be referred to here, although it means the transference of certain industries to more accessible regions merely, rather than a definite change of such an element as latitude. I have in mind the sudden conversion of an industry in which much labor is expended on a small amount of raw material into one where much raw material is consumed, and by the application of power-driven machinery the labor

required is greatly diminished. One remembers when a 50-shilling Swiss watch, although then still by tradition regarded as sufficiently valuable to deserve inclosure in a case constructed of a precious metal, was considered a marvel of cheapness. American machine-made watches, produced by the ton, are now encased in the baser metals and sold at some 5 shillings each, and the watch-making industry has ceased to be specially suited to mountainous districts.

In considering the differences which seem likely to arise in what we may call the regional pressures of one kind and another, pressures which are relieved or adjusted by and along certain lines of transport, I have made a primary distinction between " east-and-west " and " north-and-south " types, because both in matters of food supply and in the modes of life which control the nature of the demand for manufactured articles climate is eventually the dominant factor; and, as I have said, climate varies primarily with latitude. This is true specially of atmospheric temperature; but temperature varies also with altitude, or height above the level of the sea. To a less extent rainfall, the other great element of climate, varies with altitude, but the variation is much more irregular. More important in this case is the influence of the distribution of land and sea, and more especially the configuration of the land surface, the tendency here being sometimes to strengthen the latitude effect where a continuous ridge is interposed, as in Asia, practically cutting off " north-and-south " communication altogether along a certain line, emphasizing the parallel-strip arrangement running east and west to the north of the line, and inducing the quite special conditions of the monsoon region to the south of it. We may contrast this with the effect of a " north-and-south " structure, which (in temperate latitudes especially) tends to swing what we may call the regional lines round till they cross the parallels of latitude obliquely. This is typically illustrated in North America, where the angle is locally sometimes nearly a right angle. It follows, therefore, that the contrast of " east-and-west " and " north-and-south " lines, which I have here used for purposes of illustration, is necessarily extremely crude, and one of the most pressing duties of geographers at the present moment is to elaborate a more satisfactory method of classification. I am very glad that we are to have a discussion on " Natural regions " at one of our sederunts. Perhaps I may be permitted to express the hope that we shall concern ourselves with the types of region we want, their structure or " grain," and their relative positions, rather than with the precise delimitation of their boundaries, to which I think we have sometimes been inclined, for educational purposes, to give a little too much attention.

Before leaving this I should like to add, speaking still in terms of " east-and-west " and " north-and-south," one word more about the

essential east-and-west structure of the Old World. I have already referred to the great central axis of Asia. This axis is prolonged westward through Europe, but it is cut through and broken to such an extent that we may include the Mediterranean region with the area lying farther north, to which indeed it geographically belongs, in any discussion of this sort. But the Mediterranean region is bounded on the other side by the Sahara, and none of our modern inventions facilitating transport has made any impression upon the dry desert; nor does it seem likely that such a desert will ever become a less formidable barrier than a great mountain mass or range. We may conclude, then, that in so far as the Old World is concerned, the "north-and-south" transport can never be carried on as freely as it may in the New, but only through certain weak points, or "round the ends," i. e., by sea. It may be further pointed out that the land areas in the southern hemisphere are so narrow that they will scarcely enter into the "east-and-west" category at all—the transcontinental railway as understood in the northern hemisphere can not exist; it is scarcely a pioneer system, but rather comes into existence as a later by-product of local east-and-west lines, as in Africa.

These geographical facts must exercise a profound influence upon the future of the British Isles. Trade south of the great dividing line must always be to a large extent of the "north-and-south" type, and the British Isles stand practically at the western end of the great natural barrier. From their position the British Isles will always be a center of immense importance in entrepôt trade, importing commodities from "south" and distributing "east and west," and similarly in the reverse direction. This movement will be permanent, and will increase in volume long after the present type of purely "east-and-west" trade has become relatively less important than it is now, and long after the British Isles have ceased to have any of the special advantages for manufacturing industries which are due to their own resources either in the way of energy or of raw material. We can well imagine, however, that this permanent advantage of position will react favorably, if indirectly, upon certain types of our manufactures, at least for a very long time to come.

Reverting briefly to the equalization of the distribution of population in the wheat-producing areas and the causes which are now at work in this direction, it is interesting to inquire how geographical conditions are likely to influence this on the smaller scale. We may suppose that the production of staple foodstuffs must always be more uniformly distributed than the manufacture of raw materials, or the production of the raw materials themselves, for the most important raw materials of vegetable origin (as cotton, rubber, etc.) demand special climatic conditions, and, apart from the distribution of energy, manufacturing industries are strongly influenced by the

distribution of mineral deposits, providing metals for machinery, and so on. It may, however, be remarked that the useful metals, such as iron, are widely distributed on or near regions which are not as a rule unfavorable to agriculture. Nevertheless, the fact remains that while a more uniform distribution is necessary and inevitable in the case of agriculture, many of the conditions of industrial and social life are in favor of concentration; the electrical transmission of energy removes, in whole or in part, only one or two of the centripetal forces. The general result might be an approximation to the conditions occurring in many parts of the monsoon areas—a number of fairly large towns pretty evenly distributed over a given agricultural area, and each drawing its main food supplies from the region surrounding it. The position of such towns would be determined much more by industrial conditions, and less by military conditions, than in the past (military power being in these days mobile, and not fixed); but the result would on a larger scale be of the same type as was developed in the central counties of England, which, as Mackinder has pointed out, are of almost equal size and take the name of the county town. Concentration within the towns would, of course, be less severe than in the early days of manufacturing industry. Each town would require a very elaborate and highly organized system of local transport, touching all points of its agricultural area, in addition to lines of communication with other towns and with the great " north-and-south " lines of world-wide commerce, but these outside lines would be relatively of less importance than they are now. We note that the more perfect the system of local transport the less the need for points of intermediate exchange. The village and the local market town will be " sleepy " or decadent as they are now, but for a different reason; the symptoms are at present visible mainly because the country round about such local centers is overwhelmed by the great lines of transport which pass through them; they will survive for a time through inertia and the ease of foreign investment of capital. The effect of this influence is already apparent since the advent of the " commercial motor," but up to the present it has been more in the direction of distributing from the towns than collecting to them, producing a kind of " suburbanization " which throws things still further out of balance. The importance of the road motor in relation to the future development of the food-producing area is incalculable. It has long been clear that the railway of the type required for the great through lines of fast transport is ill adapted for the detailed work of a small district, and the " light " railway solves little and introduces many complications. The problem of determining the direction and capacity of a system of roads adequate to any particular region is at this stage one of extraordinary difficulty; experiments are exceedingly costly,

and we have as yet little experience of a satisfactory kind to guide us. The geographer, if he will, can here be of considerable service to the engineer.

In the same connection, the development of the agricultural area supplying an industrial center offers many difficult problems in relation to what may be called accessory products, more especially those of a perishable nature, such as meat and milk. In the case of meat the present position is that much land which may eventually become available for grain crops is used for grazing, or cattle are fed on some grain, like maize, which is difficult to transport or is not satisfactory for bread making. The meat is then temporarily deprived of its perishable property by refrigeration, and does not suffer in transport. Modern refrigerating machinery is elaborate and complicated, and more suited to use on board ship than on any kind of land transport; hence, the most convenient regions for producing meat for export are those near the seacoast, such as occur in the Argentine or the Canterbury plains of New Zealand. The case is similar to that of the accessible coal field. Possibly the preserving processes may be simplified and cheapened, making overland transport easier, but the fact that it usually takes a good deal of land to produce a comparatively small quantity of meat will make the difficulty greater as land becomes more valuable. Cow's milk, which in modern times has become a "necessary of life" in most parts of the civilized world, is in much the same category as meat, except that difficulties of preservation, and therefore of transport, are even greater. That the problem has not become acute is largely due to the growth of the long-transport system available for wheat, which has enabled land round the great centers of population to be devoted to dairy produce. If we are right in supposing that this state of things can not be permanent the difficulty of milk supply must increase, although relieved somewhat by the less intense concentration in the towns; unless, as seems not unlikely, a wholly successful method of permanent preservation is devised.

In determining the positions of the main centers, or, rather, in subdividing the larger areas for the distribution of towns with their supporting and dependent districts, water supply must be one of the chief factors in the future, as it has been in the past; and in the case of industrial centers the quality as well as the quantity of water has to be considered. A fundamental division here would probably be into districts having a natural local supply, probably of hard water, and districts in which the supply must be obtained from a distance. In the latter case engineering works of great magnitude must often be involved, and the question of total resources available in one district for the supply of another must be much more fully investigated than it has been. In many cases, as in this country,

the protection of such resources pending investigation is already much needed. It is worth noting that the question may often be closely related to the development and transmission of electrical energy from waterfalls, and the two problems might in such cases be dealt with together. Much may be learned about the relation of water supply to distribution of population from a study of history, and a more active prosecution of combined historical and geographical research would, I believe, furnish useful material in this connection, besides throwing interesting light on many historical questions.

Continued exchange of the "north-and-south" type, and at least a part of that described as "east-and-west," gives permanence to a certain number of points where, so far as can be seen, there must always be a change in the mode of transport. It is not likely that we shall have heavy freight-carrying monsters in the air for a long time to come, and until we have the aerial "tramp", transport must be effected on the surfaces of land and sea. However much we may improve and cheapen land transport, it can not in the nature of things become as cheap as transport by sea. For on land the essential idea is always that of a prepared road of some kind, and, as Chisholm has pointed out, no road can carry more than a certain amount; traffic beyond a certain quantity constantly requires the construction of new roads. It follows, then, that no device is likely to provide transport indifferently over land and sea, and the seaport has in consequence inherent elements of permanence. Improved and cheapened land transport increases the economy arising from the employment of large ships rather than small ones, for not only does transport inland become relatively more important, but distribution along a coast from one large seaport becomes as easy as from a number of small coastal towns. Hence the conditions are in favor of the growth of a comparatively small number of immense seaport cities like London and New York, in which there must be great concentration not merely of work directly connected with shipping, but of commercial and financial interests of all sorts. The seaport is, in fact, the type of great city which seems likely to increase continually in size, and provision for its needs can not in general be made from the region immediately surrounding it, as in the case of towns of other kinds. In special cases there is also, no doubt, permanent need of large inland centers of the type of the "railway creation," but under severe geographic control these must depend very much on the nature and efficiency of the systems of land transport. It is not too much to say (for we possess some evidence of it already) that the number of distinct geographical causes which give rise to the establishment and maintenance of individual great cities is steadily diminishing, but that the large seaport is a permanent and increasing necessity. It follows that aggregations of

the type of London and Liverpool, Glasgow and Belfast, will always be amongst the chief things to be reckoned with in these islands, irrespective of local coal supply or accessory manufacturing industries, which may decay through exhaustion.

I have attempted in what precedes to draw attention once more to certain matters for which it seems strangely difficult to get a hearing. What it amounts to is this, that as far as our information goes the development of the steamship and the railway, and the universal introduction of machinery which has arisen from it, have so increased the demand made by man upon the earth's resources that in less than a century they will have become fully taxed. When colonization and settlement in a new country proceeded slowly and laboriously, extending centrifugally from one or two favorable spots on the coast, it took a matter of four centuries to open up a region the size of England. Now we do as much for a continent like North America in about as many decades. In the first case it was not worth troubling about the exhaustion of resources, for they were scarcely more than touched, and even if they were exhausted there were other whole continents to conquer. But now, so far as our information goes, we are already making serious inroads upon the resources of the whole earth. One has no desire to sound an unduly alarmist note, or to suggest that we are in imminent danger of starvation, but surely it would be well, even on the suspicion, to see if our information is adequate and reliable and if our conclusions are correct; and not merely to drift in a manner which was justifiable enough in Saxon times, but which, at the rate things are going now, may land us unexpectedly in difficulties of appalling magnitude.

What is wanted is that we should seriously address ourselves to a stock taking of our resources. A beginning has been made with a great map on the scale of one to a million, but that is not sufficient; we should vigorously proceed with the collection and discussion of geographical data of all kinds, so that the major natural distributions shall be adequately known, and not merely those parts which commend themselves, for one reason or another, to special national or private enterprises. The method of Government survey employed in most civilized countries for the construction of maps, the examination of geological structure, or the observation of weather and climate is satisfactory as far as it goes, but it should go further and be made to include such things as vegetation, water supply, supplies of energy of all kinds, and, what is quite as important, the bearings of one element upon others under different conditions. Much, if not most, of the work of collecting data would naturally be done as it is now by experts in the special branches of knowledge, but it is essential that there should be a definite plan of a geographical survey as a whole, in order that the regional or distributional aspect

should never be lost sight of. I may venture to suggest that a committee formed jointly by the great national geographical societies, or by the International Geographical Congress, might be intrusted with the work of formulating some such uniform plan and suggesting practicable methods of carrying it out. It should not be impossible to secure international cooperation, for there is no need to investigate too closely the secrets of anyone's particular private vineyard—it is merely a question of doing thoroughly and systematically what is already done in some regions, sometimes thoroughly, but not systematically. We should thus arrive eventually at uniform methods of stock taking, and the actual operations could be carried on as opportunity offered and indifference or opposition was overcome by the increasing need for information. Eventually we shall find that " country planning " will become as important as town planning, but it will be a more complex business, and it will not be possible to get the facts together in a hurry. And in the meanwhile increased geographical knowledge will yield scientific results of much significance about such matters as distribution of populations and industries, and the degree of adjustment to new conditions which occurs or is possible in different regions and amongst different peoples. Primary surveys on the large scale are specially important in new regions, but the best methods of developing such areas and of adjusting distributions in old areas to new economic conditions are to be discovered by extending the detailed surveys of small districts. An example of how this may be done has been given by Dr. Mill in his Fragment of the Geography of Sussex. Dr. Mill's methods have been successfully applied by individual investigators to other districts, but a definitely organized system, marked out on a carefully matured uniform plan, is necessary if the results are to be fully comparable. The schools of geography in this country have already done a good deal of local geography of this type, and could give much valuable assistance if the work were organized beforehand on an adequate scale.

But in whatever way and on whatever scale the work is done, it must be clearly understood that no partial study from the physical, or biological, or historical, or economic point of view will ever suffice. The urgent matters are questions of distribution upon the surface of the earth, and their elucidation is not the special business of the physicist, or the biologist, or the historian, or the economist, but of the geographer.

THE EARLIEST FORMS OF HUMAN HABITATION AND THEIR RELATION TO THE GENERAL DEVELOPMENT OF CIVILIZATION.[1]

By Prof. Dr. M. HOERNES.

According to a conception at present in vogue the main currents of human civilization have developed along certain simple lines, of which the starting point, the several halts, and the end can be readily learned. It is assumed that the different groups of mankind must present the same forms, in similar order, according to some sort of arbitrary law. Thus there have been mapped out for the history of economics, of implements, costumes, habitation, morals, law, and religion, certain strict and definite plans, which have been drawn more from a priori reasoning and a limited experience than from a wide knowledge of facts. These classifications, which may be readily replaced by other similar ones, had nevertheless the advantage, like all classifications, which are equally inexact, that they afforded for the progress of investigation a better basis than when the material is in disorder and fancy turned free. These classifications, however, were not altogether inexact, but were merely inadequate for general application so as to be extended to all parts of the globe and to all groups of mankind. When properly limited and used judiciously, they present every evidence of being parts or fragments of the truth to which, in order to make them complete, other fragments should be constantly added until the highest possible degree of knowledge is attained.

As regards the history of human habitation, it is believed that at a certain period there was an age of caverns when man dwelt exclusively in the natural excavations of rocky regions. Later, when the earliest forms of buildings appeared, the circular structure was everywhere employed before those of quadrangular forms, wooden buildings before those of stone, etc. At the very dawn of evolution, man, it is thought, must have dwelt in hollow trunks of trees or in the tops of high trees. But we can make no positive assertions concerning that most remote stage of evolution. In all lines of evolution the beginning belongs to the domain of imagination; its suggestions

[1] Translated by permission from " Scientia, International Review of Scientific Synthesis," published by Messrs. Williams & Norgate, London, No. 3, 1911, pp. 94–104.

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may be guided and defended, but as theories they can not be established with evidence by exact science.

For the habit of dwelling in the tops of trees reference is made to the life of anthropoid apes. But the animal or semianimal ancestor of man did not descend from the tree in order to become a man. He dwelt on terra firma before his transformation into man, else he could not present such physical divergencies from the present anthropoid apes. It is true that we incidentally find certain savage peoples who still live in trees, but this kind of dwelling accords well with the building of huts. It constitutes chiefly a temporary safe asylum in times of danger, not a fixed residence. It is a secondary form of adaptation, the same as the pile dwellings. Man by origin is neither a climber, like the anthropoids, nor an aquatic animal, like the beaver, but he has learned to change the location of his home to increase his safety, either raising it upon high trees or transferring it from terra firma to locations over the water according as circumstances or necessity may call for one or the other of these forms. But in either case he already had the hut complete and sought for it a new foundation so that he might, at will, connect himself with or separate himself from terra firma, in one case by means of a ladder, in the other by that of a bridge. In this case, therefore, there appears no primitive form of human habitation. And this applies with still greater reason to the dwelling in hollow trees, for from what we know about savage peoples of to-day trees never constitute permanent homes, but at the most are but a passing shelter.

An analogous, if not identical, fact is pointed out in favor of troglodytism (cave dwelling). This might have been a primitive form of habitation, for nature has here united all the elements of a substantial and clean residence. There is a floor, roof, walls, often also interior divisions, covered vestibules, sunny terraces, sometimes also sheltered places hardly accessible in the rocky walls, passages running deep into the mountain and affording hiding places and refuges. As a matter of fact, in rocky regions rich in caverns these advantages early became known and were abundantly utilized during long ages. But these do not exist everywhere, and for this reason alone we can not speak of an epoch when cave dwellings were general. Moreover, the earliest human hordes were certainly too unsteady and wandering to remain attached through the entire year to this natural immovable kind of shelters. Their habit of hunting big game would not permit them such a high degree of permanent settlement. Even to-day in studying certain very primitive hunting peoples, such as the Veddas of Ceylon, we find that they seek out the rocky parts of their hunting territory only during the rainy season when they may camp in the excavations and under shelter of the rocks.

The choice of a dwelling place and of a form of building, in order to render it habitable, depends upon three factors of adaptation: (1) The nature of the ground, (2) the manner of living, and (3) the general state of civilization. These are the conditions to which everywhere the location and the form of the habitation are submitted. This accounts for all geographical and historical divergencies. In the earliest times civilization was uncertain and of no importance, while the nature of the ground and the kind of life played a very great part. The first of those factors determines chiefly the form and the second fixes the location of the dwelling. Fishermen and shell-fish eaters, for instance, live during the entire year along the seashore, but the ichthyophags of Caramania (Asia Minor) and Gedrosia (Beluchistan), as also the inhabitants of the Red Rocks of Menton (France) during the glacial period, were troglodytes (cave dwellers), while the Fuegians are obliged to build huts, just as certain of the inhabitants of the seacoast of Denmark had done whose kitchen-middens have survived. In regions of forests and steppes troglodytism is limited by the mobility of game.

Thus, cases, which might be considered as the only form of residence of the peoples of western Europe at the end of the paleolithic period, have furnished interesting information on the construction of huts through the drawings recently discovered in many places. I refer to the curious sketches which were first found graven on the walls of the cavern of Combarelles, then, painted red, in the interior of the cavern of Font-de-Gaume in the Dordogne (France), and brought to light by Messieurs Capitan and Breuil. Soon after that similar drawings were found in other caves (graven, in Bernifal; painted red, in Marsoulas). These drawings are figures of dwellings, sometimes showing a substructure with a central pole, and occasionally also with props and girders on either side. The explorers of the French caverns express no doubt but that these figures are crude representations of primitive huts ("rudimentary images of huts," Breuil), which obviously could not have been built inside the caverns and probably also not in their vicinity. In the cave of Marsoulas, above the drawing of such a hut, there is line of dots, in which Breuil sees the representation of foliage to figure the roof. Less significant are the "marks in form of huts" painted in the cavern of La Mouthe (Dordogne), Altamira and Castillo (North Spain); the drawing of these two caverns might be considered as images of interlaced bucklers. Equally uncertain are the "red dwelling figures" of the cavern of Niaux (Briège). Somewhat doubtful is the meaning of the carvings on bone and reindeer antlers found in the region of the caverns. Only the drawings mentioned in the first place can be admitted as valid proofs in favor of the theory of the building of huts at the end of the paleolithic period. The figures

of Combarelles often appear in parallel pairs, having between them the figure of an animal. In the cavern of Font-de-Gaume there are some of these drawings on the body of a bison, in the cavern of Bernifal there are two others on the body of a mammoth, while elsewhere the bodies of animals have represented upon them projectile arms and human hands, or their outlines.[1]

Thus, at the end of the paleolithic period the hunters of the closing glacial age dwelt not only in caves but also in huts; in the latter probably during their long tours over the hunting territory, which took them far away from the region of the caverns and obliged them to construct artificial shelters. These were, as far as we can judge, in keeping with the state of civilization which was comparatively not at all a low one, as the excavations in the caverns frequently show. It is not known whether these huts rested upon an artificial base or directly upon the surface of the ground, for the drawings show only the exterior view. Both alternatives are possible, but the second is the more probable. It would be in keeping with the state of civilization, as also with the climatic conditions, that these primitive structures should be on a higher plane than the humblest beginnings of architecture, represented among the low hunting races of to-day, for instance, the screen dwellings (*paravent*) of the Negritos in the Philippine Islands or the summer shelters (*toits d'été*) of the Veddas of Ceylon. But they have in common with these rudimentary means of protection against wind and weather the quadrangular form; for the screens and summer shelters of these Asiatic races consist of a quadrangular framework into which are intertwined brushwood and foliage. These frames included oblique stakes to sustain the roof. The huts of the paleolithic hunters of western Europe had two parallel sides at the roof like those of the Seminoles of the south of North America. The sustaining poles were in the center.

The nature of the floor was an important matter. On the drawings it is usually figured by squared tree trunks, and according to Matthews such is also the construction of the floor in the huts of the Seminoles,[2] while in the screens of the Negritos and shelters of the Veddas it is made of foliage and straw. The huts were the habitations of the men; the summer shelters, of the hunters; while the caves were the winter residences where the women, children, and old people

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[1] The cave-dwelling figures referred to are nearly all reproduced in the work of Cartailhac and Breuil, La Caverne d'Altamira, Monaco, 1906; Combarelles and Font de Gaume, p. 31, fig. 17; Bernifal, p. 24, fig. 11; Marsoulas, p. 30, fig. 16; Altamira, p. 63, figs. 46 and 47. Niaux: L'Anthropologie, vol. 19, 1908, p. 38, fig. 21. Castillo Alcalde del Rio, Pinturas y Grabadas, Table 9. Animals between the huts at Combarelles: Revue d'École d'Anthropologie, vol. 12, 1902, p. 45, fig. 12. Huts on the body of an animal at Font de Gaume, ibid., Table 1, fig. 2. The same at Bernifal, ibid., vol. 13, 1903, p. 203.

[2] See also Cartailhac and Breuil, loc. cit., p. 163 (fig. 2 represents a Seminole hut without floor, after MacCauley)

lived the whole year round, probably also the shamans and their pupils, where the art of drawing was carried on and where also the dead were often interred.

" Circular structures " do not appear to be represented. They certainly constitute a very ancient, and in later historic times, an archaic form of construction. But when they are met with among people who are exclusively hunters it may be assumed that they have been borrowed from other spheres of civilization. Such are the foliage huts of the pigmy races of the virgin forests of equatorial Africa, described by Stanley and Stuhlmann; perhaps also the wood, stone, and snow huts of the Eskimos; in the West these Arctic peoples also inhabit quadrangular houses of boards, covered with earth. The circular form of construction has been considered as the oldest and much inferior to the quadrangular; this assumption, however, as has been seen, seems not to be absolutely correct. The circular form appeared spontaneously when a single vertical pole was used as a support, from the top of which the roof radiated out at equal distances, as in the conical skin tents of the prairie tribes of North America. It also finds ready use in semisubterranean structures, as in ancient Europe, North America, etc. As the primitive subterranean habitations are usually round, the walls, made of posts, foliage, and clay, are likewise circular, and the roof of straw, reeds, or similar materials, is conical. Such are those in ancient Europe, while in other parts of the world they are sometimes different, though still similar. This round hut, which in reality is merely a covered hearth, has an incredible power of persistence. Its history, in a word, is that of the oldest civilization, and yet it seems to have begun only with a rise in culture, and even then its superiority was early contested by the quadrangular form of construction. The huts or houses of the neolithic village of Grossgartach in Wurttemberg were quadrangular and these are obviously not the only ones, for all the houses of the lake dwellings of the neolithic and bronze ages on the lakes of the Alpine European countries were also of similar shape.

Of the Hallstatt and la Tène periods there are extant in western and central Europe numerous remains of quadrangular structures; but by the side of these the circular building is never absent. In the region of Heilbrunn the quadrangular houses of Grossgartach were succeeded by the round huts of the bronze age, and these were again followed by quadrangular houses. Most of the dwellings of the pre-Roman period still show circular foundations of varied depth. In the trench of Gerichstetten, near Baden, which dates from la Tène period (second or first century B. C.), by the side of a deep well in the form of a funnel were found two quadrangular houses, one of which was made of posts and intertwined wickerwork, while the other rested on limestone sockets a meter high.

Strabo described the round huts of the Gaulic Celts made in the form of cupolas of boards and wickerwork with high roofs; however, in their towns they had only quadrangular buildings which, at Bibracte, had no exact rectangular outline. The poor Germans of the towns at the time of Tacitus built rectangular houses of posts, the walls being formed of intertwinings filled out with painted clay; each house was surrounded by a wide, free space, " ut fons, ut campus, ut nemus placuit " (where a spring, a meadow, a grove pleased them). But alongside they also had subterranean rooms, probably round ones, covered with dung, which served as caves, as retreats, and during the severe colds as winter dwellings, and were difficult of discovery in case of a hostile attack. Proofs of the existence of these circular structures are legion; they have even continued in Europe to the present. But the quadrangular structure made its appearance so early that it can not be given a specified origin, for instance, a southern, as some claim (O. Montelius, S. Müller).[1]

On the other hand, certain archeologists have the contrary tendency, namely, to derive from the north of our continent for the south of Europe a specified form of quadrangular house, the " Megaron type," so termed from the poems of Homer as well as after the ruins of Troy, Tirynth, and Mycenæ. We shall confine ourselves to a brief discussion of this question only, for it is impossible to treat in an essay like the present, even rapidly and in a sketchy manner, such a vast subject as the oldest forms of building in all its aspects. But it may be worth while to show by an interesting example how at present an effort is made from various sides to put forth and consider as proofs certain affinities in the history of art and civilization, due to certain analogies and coincidences (in which the anthropologist would at a glance discern the results of convergent adaptations), ascribing them to ethnic or at least racial characteristics, while most frequently these hypotheses are the offspring of the deep wish of their authors.

The Homeric and Mycenæan " Megaron " was a rectangular structure, originally consisting of one room, with a door on one of the narrow

[1] Grossgartach : A. Schliz, Das steinzeitliche Dorf, Stuttgart, 1901. Exclusively quad-rangular huts on piles : L. Schumacher, Untersuchung von Pfahlbauten des Bodensees, published in Veroeffentlichungen Badischer Sammlungen, II, 1889. Round huts of the bronze age at Heilbrunn : Schliz, Württembergische Vierteljahrschrift für Landes-geschichte, W. F. XVII, 1908, p. 438. The quadrangular houses of the Halstatt period in the same region : Ibid, p. 439, and Mitteilungen der Anthropologischen Gesellschaft of Vienna, XXXIII, 1903, p. 311 (compare also Schliz, Fundbauten aus Schwaben, IX, 1901, p. 21 seq., and XIII, 1905, pp. 30–57), also Soldan, Annalen des Vereins für Altertumkunde von Nassau, XXXI, 1900, p. 145 seq.; XXXII, 1902, B., pp. 35 and 59. Gerichtstetten Schumacher, Veröffentlichungen Badischer Sammlungen, II, 1899, pp. 75–84. Round huts of the Gauls. Strabo, IV, 4, 3 (Cæsar mentions roofs of straw, Cæsar, Gallic War, V, 43, 6 : of wood and straw, Vitruvius, II, 1, 3) ; of the Germans; Tacitus, Germania, chapter 16. Quadrangular structures of the so-called European origin : O. Montelius, Archiv für Anthropologie, 1895, p. 548 ; S. Müller, Urgeschichte Europas, p. 99. All these forms and the problems connected with them are more fully discussed in my Natur- und Urgeschichte des Menschen, Vienna, 1909, II, pp. 27–132.

sides. In front of the door was a small open vestibule which must have served to protect the entrance, as evidenced by a projecting roof. In the center of the principal chamber was the hearth, and above it, in the gabled roof, an opening to let out the smoke. The corners of this opening rested on posts which were placed around the hearth. In this simplest form it was the house of a small rural family, but it also constituted the seignorial house, in the citadels which were erected on the continent and surrounded with Cyclopean walls, in Argolis and Asia Minor, while the palaces of Crete show no trace whatever of this kind of structure. In the Hellenic period the Megaron type gave rise to the Greek temple, especially the temple with pilasters jutting out (Templum in antis). It appeared, also, as an element in the great buildings of Hellenistic times, as at Pergamum and Priene. At least it could not suffice for the growing needs which a dwelling of a modern period had to satisfy.

These are well-known facts. But they were employed to establish a prehistoric phase of the " Megaron " type. Crete and the neighboring Orient were left out of consideration because they presented nothing analogous; besides, this house with a hearth and a gable end suited a climate colder than that of Egypt or western Asia. R. Henning (Das deutsche Haus in seiner historischen Entwicklung, 1882) found an affinity between the old German and old Greek houses, though so far he could refer for the Greek house to the templum in antis (the " Megarons," of Troy, etc., have not yet been discovered) and the Homeric description of the house of Odysseus and as northern analogies could only quote the Norwegian peasant houses of the sixteenth and seventeenth centuries A. D.

The resemblances of the houses of the North with the " Megaron " type are slight and belong to later periods, if not entirely to modern times. A house of the Viking period (800–1050 A. D.) at Augerum in Bleking, south Sweden, had around the hearth, which stood in the center, four posts supporting the open roof for the passage of the smoke. In front of the entrance two posts upheld the projecting roof. The plan of this building was not quadrangular, but oval, nearly round (Montelius, Kulturgeschichte Schwedens, p. 238, fig. 451). The German house, discovered and described by C. Schuchhardt (Prehistorische Zeitschrift, I, 1909, pp. 209 and 59) on the Römerschanze at Potsdam, a trench which was in later times occupied by the Slavs, presented the greatest similarities to the " Megaron," but the date of that house, which consisted of a frame of wickerwork, filled out with earth, is doubtful; it dates, at the earliest, from the beginning of the Christian era. There is, then, no basis for calling the Megaron type the building form of " German antiquity " or, as Henning does, " The antique Aryan form." It is probable that

there was not one common typical form of "German antiquity" or of the "primitive Aryans," but several forms which were not marked by national or ethnic characteristics, but merely presented diverse forms of adaptation to the ground, the climate, the economic conditions, etc.; of these the Megaron type appeared very early in southern Europe and Asia Minor; in Troy of Hissarlik as early as the third century B. C., while in northern and central Europe much later—not before the beginning of our era. More than this at present can not be asserted. The connection assumed by Schuchhardt and others may hold good, but it can not yet be demonstrated, and we should rather search for another origin for the Megaron type than north Germany or Scandinavia.

There is no lack in other parts of the world of similarities with the Megaron form of construction, which are not inferior to the house of the age of the Vikings of Augerum. The Mandans of North America had round houses, raised upon a slight excavation, with a central hearth surrounded by posts, and letting out the smoke through an opening in the roof. There again the door had a horizontal projecting roof supported by pillars. The neighboring races of the Missouri adopted this type of house.

The opening in the roof resting on posts above the hearth is also found elsewhere in North America, in the Hinterland of the Northwest, and even serves as an entrance into the subterranean house. This is merely to show that similar forms may be met with everywhere under certain conditions, and no attempt is made to establish any relation whatever between the Old and the New World. According to the results of excavations in Bœotia and Thessaly, the evolution of the habitation in northern Greece advanced from the round hut to the oblong quadrangular construction through the intermediary of the oval. At Orchomenes the neolithic huts were round, those of the second century, B. C., elliptic, while those of the middle of the same century were rectangular. But in southern Thessaly there were already in the neolithic age houses similar to the "Megaron."[1] It is probable that the Megaron type developed spontaneously in northern Greece as analogous forms did in other regions near and distant. Its characteristic elements—opening in the roof and the penthouse—may have already appeared in the circular form, as is shown by the instance of the Mandans.

[1] The house of Mandares (according to Morgan) in W. Krickeberg, Illustrierte Völkerkunde, edited by G. Buschan, p. 34, fig. 4. Orchomenes: Bulle. Abhandlungen der Bayrischen Akademie der Wissenschaften, Philosophisch-historische Klasse, 1907, XXIV, 2. Megaron of Northern Thessaly : Tsuntas, Athens, 1908.

FEUDALISM IN PERSIA: ITS ORIGIN, DEVELOPMENT, AND PRESENT CONDITION.[1]

By JACQUES DE MORGAN, Paris.

The Iranian plateau is one of the very few countries of the world of which we can with authority affirm that we know its first inhabitants. We know that in glacial times it was inaccessible,[2] and even after the melting of the snow which covered it throughout the Pleistocene period it still remained barren[3] during many centuries, perhaps for even thousands of years. When the tribes of Medes came there they probably trod on virgin soil.

We include among the Medes those hordes which, taking the lead in the Iranian[4] movement, first of all invaded Hyrcania, crossed the low plain south of the Caspian Sea, occupied the mountains of Elburz, and advanced on the Persian plain as far as the region where the cities of Kashan, Hamadan, and Kermanshah now stand.

When the tide of invaders reached the mountains of Kurdistan it encountered some peoples who, come probably in early times from the valley of the Tigris or the north of western Asia,[5] settled in the valleys; they retreated before the invasion and spread out toward the west. Perhaps in this movement of peoples we might see the origin of the Cassite dynasty of Babylonia,[6] whose founder Gandish or Gaddash ruled from about 1761 to 1746 B. C.[7]

But the invasion of the Medes was not stopped there; to the north, Armenia, all of the upper Tigris and the upper Euphrates Valleys were successively occupied, and the Iranian bands penetrated into Asia Minor and as far as Oronte,[8] the homes of the Hittites.[9]

[2] J. de Morgan, Le Plateau iranien pendant l'époque Pléistocene, in Rev. École d'Anthrop. de Paris, June 6, 1907, pp. 213–226.

[3] J. de Morgan, Les Premières Civilisations, 1909, p. 181.

[4] Throughout this article we consider peoples from the standpoint of their linguistic characteristics only.

[5] J. de Morgan, Prem. Civ., 1909, p. 175 sq.

[6] A first invasion of Cassites in the nineteenth year of Samsilouna (about 1900 B. C.) had been hurled back. Cf. Dhorme, Les Aryens avant Cyrus, in Conf. St. Etienne, 1910–11, p. 73.

[7] Cf. Thureau-Dangin, Journ. Asiat., 1908, p. 117.

[8] Cf. Dhorme, op. cit., p. 70.

[9] Cf. Dhorme, op. cit., p. 61, and Winckler, Orient. litt. Zeitung, 1910, col. 291.

While the movement of the Medes was executed in the north, another branch of the Aryan group, the Persians, advanced toward the southeast and south and occupied the countries near the Persian Gulf and Persia proper.[1]

Since that period, that is, since about 4000 B. C., the nature of the population of Persia has been modified [2] only in Media, the invasion of which by the Turks, only a thousand years ago, drove back the ancient inhabitants on their congeners in the mountains of Kurdistan.[3]

From the twentieth century before our era western Asia has thus been shared by two very distinct elements, the old races, Semitic and aborigines (Elamites, Hittites, Caucasians, etc.) in the west, and the newcomers of the Aryan group in the north and east.[4]

Among these two elements the principles of government show some decided differences. While in the Semitic country feudalism was based on absolute obedience to suzerain and entire ownership by the master, among the Aryans the same system of government rested on the great vassals or companions of the supreme chief.[5] This nobility included the younger branches of the royal family and the principal chiefs of tribes which had taken part in the conquest. It constituted a sort of council which governed with the sovereign.[6] The seigniors themselves in their provincial governments surrounded themselves with their principal subordinates, descendants of those who had served under their ancestors at the time of the invasion.

After the conquest each of the chief vassals was granted or received a territory proportionate to the importance of his tribe, and the same was done for each of the clans, then for the families. Thus a kind of complete hierarchy was established from the owner of a village or a group of tents up to the supreme master.

The empire belonged primarily to the Medes; probably because they were the most numerous and the first comers. But their forces being spread all the way from Parthia to the borders of Oronte, the Persians, whose forces were more concentrated, snatched away their supremacy. This revolution was otherwise of no consequence from the point of view of social organization. Cyrus governed as king of

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[1] Provinces of Seistan, Kerman, Shiraz, Ispahan, bordering the mountains north of the Gulf of Persia as far as Susiana.

[2] We do not intend to speak of the sporadic peoples, Jews, Chaldeans, Arabs, Afghans, Hindus.

[3] Some authors are of the opinion that the Cassites were Aryans. (Cf. Dhorme, op. cit., p. 66 sq.) In that case they would have preceded the Medes and Persians in Iran and represent the first human wave that traversed the Persian Plateau.

[4] In the Aryan group we include peoples speaking languages related to the Sanskrit, Greek, Latin, Germanic, Persian, etc.

[5] The same traditions are found among all the Aryan peoples who later invaded Europe, the Germans among others.

[6] Proofs of the existence of this council of nobles are numerous in the history of Persia; but it is very interesting to find the same constitution among the Harri, an Aryan caste which, about the epoch of Rameses II, governed the country of the Mitanni. Cf. Dhorme, op. cit., p. 67.

the Persians and Medes, while his ancestors had been ruled by the king of the Medes and Persians. The chief men of the realms kept their estates and their rank, and, according as they were either of Persian or Medic origin, they continued to compose the royal council. It is true that at first they were less favored in what concerned important affairs, but little by little equilibrium was established and the Persians and Medes became a single nation.

The Achæmenian sovereigns divided their empire among satraps, for the most part hereditary proprietors of the land, whom it would be a great injury to have as governors, in the sense given to that title in our day. The seigniors of less importance conserved their rights, their privileges, their lands, as well as the moral situation they had in the State. This aristocracy was a curb on the royal power; the kings dreaded it and willingly or by force governed under it.

To be sure, in times of trouble or revolt many members of this nobility, both great and humble, would be losers;[1] but these rigorous measures applied only to individuals and the principles were not in the least broken. As a result of traditional influence, where a king could be found to preserve it, the feudal organization was much more favored than opposed by the Achæmenidæ. Moreover, feudalism insured great security through the loyalty of subjects of the empire.

The Macedonian Conquest brought the first great change which still survives in the political and social life of Persia. The Greeks must have a governor for themselves if they would preserve the empire. Nearly all of the great satraps, Greeks or natives, were appointed according to the governmental views of the conqueror and his followers. Macedonian garrisons occupied the principal cities to maintain the obedience of the inhabitants, to lend a strong hand to the governors, and at the same time to watch their conduct. The Persians who under Alexander performed the duties of satraps were no more than officials, obedient to higher powers. As to the common aristocracy, it felt this change in power in a much less degree, for its privileges were continued, its property remained in its possession, and perhaps its local influence was even increased by the debasement of the chief seigniors.

The defeat of Darius Codomanus brought to the high Iranian nobility the loss of its army, which was the chief source of its riches and of its credit. After Alexander, the principal officers were Greeks, commanding the troops of their nations, and if at times certain Persian nobles served in the Macedonian army it was only at the head of native troops, and consequently without much authority.

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[1] See in this connection the inscription of Darius at Bisoutoun.

Most of the officers of the Achæmenian army retired to their lands, hoping to see the happy fortune of yesterday return.

The political policy of the Seleucidæ followed in all respects that of Alexander; nevertheless, the military power of these kings, no longer having the energy of the conquest, and the Macedonian forces available for an invasion being insufficient in number for continued control by force of arms, the seigniors of the times of the Achæmenidæ again took the lead and endeavored to regain their independence. Revolts became frequent in the provinces, incursions on the frontiers multiplied. There then arose, exclusive of Bactria, a considerable number of small realms, such as that of the Arsacidæ,[1] Scythian chiefs who had established themselves in the Seleucid province of Parthia,[2] such as that of Perside,[3] where the priestly character of the princes constrained the kings of Syria in some respects, and numerous small principalities, of which even the names are lost or hardly preserved in history. This was the awakening of national feudalism, and this feudalism seems to have become of more importance than ever when there suddenly occurred the conquest of Persia by the Parthians.

The Parthians were Scythian nomads, in ancient times tenting in the valley of the Ochus, a river of the Oxus Basin. About 250 B. C. they crossed the Seleucid frontier, entered the province of Parthia, and established[4] themselves there, retaining all of it, with the city of Dara,[5] as the seat of their government, the capital of their ancient patrimony. In this way they founded a small State, which for about[6] a century wrestled for its independence and increased its power somewhat.[7] Finally, Mithridates I succeeded not only in pushing back the Greek troops who had attempted to crush his rising power, but in a few years he took possession of entire Persia, some Bactrian provinces, and at the end of his reign minted money,[8] even in Syria, whose King, Demetrius Nictator, was his prisoner in Hyrcania.[9] A new empire was founded, itself based on feudalism such as was in force among the Scythian nomads. The seigniors of the new stock

[1] This name is of Persian and not Scythian origin; for we know that Darius II Ochus (405–359 B. C.) carried the name of Arsace before taking the throne. Cf. Ed. Dronin, Onamastique Arsacide.

[2] The name Parthia already existed at the time of the Achæmenidæ (Herodotus, VII, 96). It was therefore not the Parthians who had given it to him. They had taken it after the conquest of that province.

[3] Cf. Col. Allotte de la Fuye, Corolla Numismatica, 1906; Étude sur la Numismatique de la Perside, London, 1906. A memoir in which there is a complete bibliography concerning sources of history of Perside

[4] Justin, XLI, 4; Strabo, XI, ix, 2.

[5] Cf. Olshausen, Parthava and Pahlav, Berlin, 1877, p. 10, seq.

[6] From 250 to about 170 B. C. The first princes were: Arsace I (250–248), Tridate I (248–211), Arsace II (211–191), Phriapatius (191–176), and Phraate I (176–171 B. C.).

[7] Hyrcania (Province of Astrabad) and some territories in Media, at most as far as Ragae.

[8] Cf. W. Wroth, Catalogue of British Museum, Arsacides, pl. 3, figs. 7–12.

[9] Justin, XXXVI, 1.

revived some appanages. One King, Bacasis, probably of the Parthian race, imposed a tax on the Medes, and the old aristocracy was humbled by the new, the princes of Perside among others.[1] It was at about this time that were founded the principalities of Characène[2] and Elymaïde,[3] as well as the Kingdom of Armenia,[4] which later was the cause of all the wars between the Romans and the Persians.

Elymaïde and Characène had become dependent provinces of the empire, but kept the right to mint money,[5] a privilege of which only traces are found in these principalities and which Mithridates probably tolerated only because of its immediate neighborhood to Syria and the services that the dynasties of these countries had been able to render to his cause during the conflicts between Persia and the Seleucidæ.

But this changing of government did not modify the deep-seated composition of society. To the old great feudatories were joined the new, and the lesser seigniors became possessors of their lands, passing only from the authority of Greek governors to that of the newcomers. The Parthians were not concerned in feudalism as a whole for that mode of government was already in accord with their traditions.[6]

In Elymaïde, under the reign of the great king Osroè,[7] the ancient dynasty of the Kamnaskirès made place for the new princes all carrying Arsacid names,[8] dynasties which, like those of Characène,[9] could no longer from the beginning of this epoch coin money with the portrait of their ruler, the King of Kings,[10] though bearing their name in the legend. It was feudalism which started the upheaval that overthrew the Arsacid dynasty. A prince of Perside, Artaxerxes, son of Papek,[11] profiting by the instability of the throne of

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[1] Strabo, Liv. XV, ch. 3, 23. The first period of Persian numismatic autonomy commences about 220 B. C., and stops at about the epoch of the rise of the power of the Arsacidæ.

[2] Hypsaosines (about 124 B. C.) was the first prince of Characène of whom we have medals. He was doubtless the founder of his dynasty and the restorer of the city of Charax. Cf. Lucien, Macrobii XVI.

[3] The earliest medal that we know of Elymaïde is a tertadrachm of Kamnaskires (I?) struck about 160 B. C., under the reign of Antiochus IV or of Demetrius I of Syria.

[4] Mithridates I had given the crown of Armenia to his son Valarsace. Cf. Moïse de Khoresie, Langlois Translation, II, 3–7.

[5] Cf. E. Babelon, Sur la numismatique et la chronologie de Characène, in Journ. d'archéol. et de numismatique; Athens, 1848, I, pp. 381–404. Col. Allotte de la Fuye, Sur la numismatique de l'Elymaïde dans Mém. Deleg. en Perse, 1905, Rev. numism., 1902, La Dynastie des Kamnaskirès.

[6] Toward the end of the dynasty the Parthian nobility called Vononès II to the throne, when that prince was viceroy of Media, and incited Méherdatès to revolt against Gotarzes, which brought Cinnamus to the throne, which recalled Artaban III, after having dethroned him, etc.

[7] J. de Morgan, Numismatique de la Perse antique, a work in preparation.

[8] Col. Allotte de la Fuye, op. cit., 1905.

[9] Cf. Ed. Dronin, Journ. Asiat., June, 1889, ed., Rev. num., 1883, 2d quarter, p. 373 seq.

[10] J. de Morgan, Num. Perse antique, in preparation.

[11] Cf. von Gudschmidt, Zeitschr. d. Deut. Gesell., 34, 734.

Persia,[1] restored the power and the religion [2] of the people of the Iranian race. From that time the Parthian nobility was humbled in its turn, and that of ancient times again acquired all its prerogatives. The Arsacides and their congeners disappeared, some took refuge in Armenia,[3] in Georgia,[4] among the Aghuanks,[5] and in other countries where some princes of their family [6] still reigned. As to the majority of the Parthian tribe, it became absorbed in the Iranian mass and left no traces.

The Persian seigniors were, one after another, called to the highest duties of the State; they reconstituted the council of nobles, who, in many instances, attained the throne. All the satraps, all the high officials, were Persians, and the principalities, reduced to obedience, ceased to issue money. In this restoration of the Iranian power the Sassanian sovereigns were encouraged by Archæmedian traditions.

The Arab invasion followed, which modified only the religion, having no effect on other institutions of the country. The Persians became Mussulmans without making any great resistance. The Ulemas were substituted for the Mazdean priests, and among the seigniors hereditary rights were transmitted as in the past, while some of the important feudatories of old set up their principalities in the realm. The Ispehbeds of Thabéristân (Mazanderan) coined money of the type of Chrosoès II but with Mussulman legends.[7]

The only effect of the invasion of the Turks in the north of Persia was to drive out the Iranians who dwelt there and to substitute the régime of the Begs for that of the Khans and the Aghas; but it affected only the open regions in the northern territories, the mountain country remaining Iranian.[8] The south and the center of Persia

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[1] At the close of the reign of Mithridates IV, numerous competitors for the throne arose in all the Provinces of the Arsacidæ, of which the power, greatly weakened by their wars against the Romans and against the barbarian peoples of the east, became diminished from day to day.

[2] The Mazdean religion was preserved pure throughout the principality of Perside whence came the Sassanian dynasty.

[3] The Arsacid dynasty of Armenia, notwithstanding its numerous quarrels with Rome, succeeded in maintaining itself for a long time after the fall of the Arsacidæ in Persia. Cf. Moïse de Khorém, Patkanian (Hist. de l'Arménie), etc.

[4] Transcaucasia was then divided into a great number of small States, which in turn passed to the Romans and the Parthians; an Arsacid branch had been established in Georgia.

[5] Cf. Patkanian, Hist. armen.

[6] One Arsacid branch ruled over the Kouchans and the Thetals (Bactria and Caboul), another over the Massagetes and the Ephina (Lepones of Tacitus), to the north of Caucasus; the Kingdom of Sacastène and of the Indus appear also to have been founded by a branch of the Arsacid family.

[7] These princes ruled at Thabéristan (country of hatchets, otherwise called woodchoppers), forest region of Mazanderan situated between the plain of Ashraf and the district of Tunékâboun, comprising the cities of Barfrush, Sari, and Amol, and limited to the south by the mountains of Elburz. This principality had completely disappeared in the Middle Ages and to-day there remains scarcely the memory of it in the country that included it.

[8] All Mazanderan, Ghilan, and Talish remained in the possession of peoples speaking Iranian dialects. Cf. J. de Morgan, Mission scientif. en Perse, 1889–1891, Vᵉ partie. Études linguistiques.

remained unchanged and preserved the feudal traditions under which the national kings were trusted, like their predecessors, with the throne.

Finally, there followed the dynasty of the Turkish Khadjars,[1] who exploited the country but did not govern it. In all districts adjacent to the principal centers,[2] in those where it was easy to oper-ate with armies, the old nobility disappeared little by little, ruined, dispossessed, deprived of important duties; but in all the remote provinces, in the mountains where the Turkomans dared not venture, the Aghas, the Khans, and the Vahlis preserved their absolute power at the expense of an annual tribute which they paid to the Crown.

Moreover, the governments of the provinces being sold at auction, it was among the landed property holders, among the Khadjar[3] princes and the high Turkoman dignitaries, among those, who in the eyes of the King, offered the highest guarantees, that the administration of the provinces was distributed, and often the seigniors of old extraction bought the government of their own dependencies in order to safeguard the interests of their families. In this case they left all their serfs in the dependency, decorating them merely with pompous titles pertaining to their new duties.

In that case, on the contrary, where the new governor owned no lands of which he had purchased the government, he attached to his suite certain clients[4] drawn from his particular domains and, in consideration of an annual rent and some gifts, granted them all the expenses of the Province, allowing to each according to the face value it offered. Very often the purchase of the same government was made by a joint company of all these officials. It mattered little whether the several members of the company had the requisite abilities for filling their offices; each district was given its vice governor, each group of villages its chief, and everyone was located with his own clients living on the country and squeezing it for all it was worth. The demands generally exceeded reasonable limits. Then the governor was changed, his followers retiring with him,

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[1] The Khadjars abandoned the old capital Ispahan and founded a new one at Teheran, near the site of ancient Ragae in order to be in the midst of the land formerly conquered by the Turks and to be near Turkomania from which in case of need they could quickly bring some tribes.

[2] The Turkoman tribe of Khadjars lived at Ak Kala (white fort) on the river Kara Su (black water), some little way to the north of the city of Astrabad on the Turkoman steppe. Exempt from taxes and loaded with favors, since the throne belonged to one of their number, this tribe lived in idleness.

[3] The Khadjar princes increased greatly in Persia, Fath-'Ali Shah had more than a hundred sons who nearly all had descendants.

[4] The civil household of a governor was composed of a hundred persons more or less, without counting the servants, ministers, chaplains, doctors, secretaries, vice governors, chiefs of police, treasurers, etc. In a military household it was more numerous still. None of these functionaries were paid, but on the contrary, it was a temporary expense to him who accepted the position.

and a new official came accompanied as before by a great number of satellites and inspired by the same thought of grasping as much as possible.

It was in this way that feudalism in these Provinces was little by little crushed out, and though some of its privileges remained, it was only by tolerance on the part of the court whose interest it was to have always at hand some persons responsible and able to pay according to the needs or fancies of any of the officials of the provincial government.

These seigniors, through fear of losing their lands,[1] crushed the people to satisfy their high position. Their only authority was that which remained over their slaves. All carried high sounding but otherwise empty titles, such as "the saber of the law, the sword of empires, the eye of justice, the backbone of power," etc. They were marshals, generals, colonels,[2] with no duties, as was well known, watching the sum poured out to the King of Kings in order to receive like honors, the only advantage of which was to give them a favored place at court, some slight protection against exactions, and the hope that there might come to them a day when they might likewise purchase a government or some authority permitting them to replenish their purses and act before others as others had acted before them.

Such was the condition of the nobility in the royal Provinces for 20 years. But it was far from true that all the Provinces thus willingly obeyed the wishes of the officials named by Teheran. Practically, the compass of many of the Provinces was limited to the principal place included in its jurisdiction, while the rest of the Province remained as before, under the authority of seigniors, obedient somewhat less to the royal officials as they were farther from the large cities, and as their land was more inaccessible.

These Vahlis, Khans, Begs, and Aghas[3] were veritable kings in their domains; they succeeded one another from father to son, receiving only as a matter of form the investiture of Teheran. They preserved an absolute freedom through presents sent at opportune times; the richest were offered the very highest guarantee, that of marrying, in consideration of a very great sum, one of the numerous daughters of the king.

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[1] Each village had its responsible chief and besides this chief the "white beards" (Rich séfid) ; above was the proprietor of the land, the Khan who often owned many villages. The land was sold only with the houses built thereon and the people dwelling on it. They estimated the value not according to the area of lands under cultivation, but according to the number of houses, each house being estimated at five persons. It was the same with the nomad tribes who estimated only by the number of tents.

[2] In the single village of Tauris there were in 1890 more than 3,000 persons bearing the title of general or higher officer.

[3] See the work on Kurd feudalism in the Middle Ages by Chéref Nâmeh, translated by D. Charmoy.

The power of these princes was unlimited and they could put to death those of their subjects (rayats)[1] who had had the misfortune to displease them. Their friends and feudatories were their officials, their functionaries whom they otherwise designated as "domestic," but who, in fact, composed their council. They never exercised the powers thus granted with cruelty or injustice. Their position itself depended on their ruling properly, since their feudatories were always ready to depose them, just as, under the Sassanians, the nobility drove the native rulers from the throne.

The peasants poured into dependencies ruled with justice[2] and the wealth of the chief as well as his military power was appreciably increased when the rayats themselves quit the territories or ruled unjustly or arbitrarily. Wealth in Persia does not depend on the ownership of land, but solely on the power to control labor to cultivate it.

Among these tribes there are some customs which, although not written, have no less the force of law, and it is often by these common laws, the antiquity of which goes back to the early period of the Iranian invasion, that cases are judged. The Koran is faithfully consulted, but its text, always very elastic, has not been interpreted in the same spirit which always has ruled among the nomads; thus it lends itself with extreme complacency to the application of old Persian customs.

The sovereigns[3] who have reigned at Ispahan, those of Iranian blood, far from seeking to crush the nobility, have made of it a governmental instrument of the first order. Likewise, resting on their feudatories and on the townsmen of cities with whom the understanding has been extremely frank, they have made Persia the richest and most powerful country of all the Orient. The wisdom and the regard for traditions which ruled at their court and which, under the Achæmenidæ and the Sassanians, had raised so high the

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[1] The rayat is rather a serf than a peasant in the meaning that we give to the latter class. The rayat, however, has over the serf the great advantage that he can quit the land without permission of his master and establish himself elsewhere. This privilege protects him from too severe exactions.

[2] I have seen some clans, where the chief was esteemed as a just man, increase in four or five years from 10 to 300 tents, and frequently also the reverse appeared.

[3] The Kings of Persia carry even to-day the title of shahan-shah ."king of kings," a title essentially feudal. Under the Sassanians, the title was written in the Semitic language, Malkân Malka, which could perhaps be read shahan-shah; under the Parthians they wrote it in Greek, Basiléos Basiléon. Under the Achæmenidæ, Khshayathiya Khshayathiyanam, whence comes the actual pronounciation, and the Achæmenidæ had borrowed from the Assyrians sar raba "great king," sar martat "king of nations," sar sa nabhar matat "king of all nations," sar sarri "king of kings." The Persians to-day have difficulty in explaining this title. To the credulous natives, they say that the sovereign is in reality the king of other kings, that in the world nothing is done without order. With foreigners their pretentions are less great. They are content to say that the name has fallen into desuetude, not taking any account of the fact that the King of Persia is still effectively king of a great number of seigniors and that his title is that which fits him the best.

honor of their country, had enabled them to organize Persia in accord with the spirit of its people, to enrich it and make it powerful in the eyes of foreigners.

But the Turkoman dynasty, on coming to the throne, broke with the old institutions, not through politics but through cupidity. Instead of trusting to feudalism it combated it because of its wealth, forcibly destroyed it wherever possible to enforce its power, replacing that system in the government of its new subjects by a hierarchy of tyrants preoccupied altogether with enriching themselves and with responding to the demands of its masters at Teheran.

All the wealth of the country was little by little absorbed by the King and his followers, by his harem, by his ruinous fancies. They lost in Persia the idea of administration, and little by little the thirst of robbers gained the entire country. There was no longer justice, because from top to bottom of the social scale the aim pursued was unjust. No longer were there works of public utility, which had been the glory of the reign of Shah Abbas. No longer was there an army, or police, for the palace of the King absorbed all the resources, and extortions, as well as the sale of valuable privileges for ready money, caused a general impoverishment of the country. The royal treasury, called the reserve of the Khadjars, was emptied, and nothing was left but the name—the jewels and the silver plate were sold, debts were incurred to pay dancers and astrologers, to maintain the 3,000 people of the harem, and to treat themselves royally in Europe as well as at home. In this way, in about a hundred years, there passed away an Empire which had merited respect for centuries.

But though the Khadjars succeeded in reversing the old order of things in all those parts of their empire which they could directly control, they made hardly any encroachment among the mountaineers and in regions far from their capital. Feudalism there survives in its full force. In Turkomania the tribes still live as in the time of Djenghis Khan and of Timour Leng, and their Beys[1] are absolute masters in their tribes. It is the same among the Aghas in certain parts of Kurdistan, among the Khans in Luristan, among the Vahlis in Pusht-i-Kuh, in the country of the Bakhtiyari, and farther still toward the east.

These are the same Bakhtiyari, seigniors of the old Iranian stock, who seek to overthrow the absolute power of the Shahan-Shah, renewing after an interval of 17 centuries, under a new form which probably, alas, will be less fortunate, the revolution which Artaxerxes I, son of Papek, the Sassanian, carried on in Persia.

A third of the Empire, if not the half of the habitable country, has always submitted to feudal rule, and entire Persia is still imbued

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[1] In Turkestan, Bai; in Azerbijan and Transcaucasia, Beg; among the Osmanlis, Bey.

with the principle of feudalism, with respect for a hierarchy which has been in force for a thousand years.

Among the seigniors whose power has been preserved safe and sound there are those who never mention the name of the King, who wait not for his approval to transmit the power from father to son, who for centuries have not turned into the treasury any tribute whatever. When these and their rayats express themselves concerning their Government there is heard nothing but maledictions.

Since 1889, when I first set foot on the soil of Persia, I have lived much among the nomads and in the military camps. Some reminders of my sojourns among these primitive people will have, I think, some interest. From an ethnographic and sociologic standpoint the story you are about to read gives an accurate account of the situation in which the latest great seigniors of Persia live. I will not attempt to describe these old dependencies or enter into all the details of the life of the inhabitants, but desire only briefly to show what their system of life is—what are their ambitions and occupations.

When, after long and tedious halts on the dusty and stony roads of the Persian plateau, you emerge from the defiles of Elburz to approach Astrabad, you see in the distance an immense plain, ending at the horizon in a blue line seeming to follow that of the Caspian Sea, which bounds the view on the left. This plain begins at the foot of some hills forming the final spurs of the great range. It seems to reach to infinity. Smooth, without the least wrinkle, of a uniform green color, it surprises by its immensity. Here and there, however, isles rise in this ocean of verdure, some knolls scarcely perceptible in the distance and lost in the hazy bluish color of the horizon. Then, with field glasses, you distinguish some small gray points, sometimes grouped, sometimes isolated, now and then joined like the windings of a great serpent. Looking closely you see the land disappear from view, always alike toward the north, and you understand why the ancient geographers considered these imperceptible limits as the end of the habitable world.

This plain is the steppe; these mounds are the vast ruins calcined by the burning of the great cities of antiquity; these grayish points show the unknown villages grouped by tribes or fixed on the borders of some watercourses which, sprinkling this immense carpet of verdure, flow out in a thousand recesses, slowly, in harmony with the majesty of the region that they traverse. This blue line of the horizon is the Empire of the Tsar.

Still advancing, you descend some low hills covered with bushes; then all at once the land becomes level and the steppe begins, covered with short grass, without a pebble, without a hillock, to break the monotony of this perfect level.

To the right and left are some small circular knolls, some decimeters at least in height, encircled by a ring about 6 feet in diameter, from which the ground appears to have been dug out in former times. You seem to see traces of child's play. These are Turkoman graves. Little by little the rains have effaced the small tumulus and filled the circular pit whence was taken out the earth of the hillock. These graves, scattered without order on this immense plain, mark the place where died those whose bleached bones rest some feet underground, near some encampment where the tribe then lived. Then, the demand for troops calling them elsewhere, the camp was left, and no one since then has stopped near these tombs. From the day when the earth received them, these beings have been forgotten forever.

We pass on, and the journey is continued with no signs of path or road, for the steppe has none; but we are guided on the march by the sun. Night falls, and the stars replace the sun to indicate the course.

Finally, at a little distance, some beams of light are seen and suddenly a pack of hounds come bounding forth. The guardians of the village are warned of our approach.

The village, otherwise of very little importance, has about 30 kibitkas, or circular tents, 5 to 8 meters in diameter, surrounded by a latticed wall made of reeds, skillfully tied together and covered with a thick felt in the form of a dome. The men, seated there smoking the tchibong, are capped with enormous hats of sheepskin, dressed in a dark blue cotton cloth, sordid and covered with grease, smelling of sheep, horse, studded with vermin; near them are their guns, and at their belts glitter three or four rows of brass scabbards. On the ground an old mat and a carpet, torn and stained. In the middle of the kibitka burns a fire of argoles, the acrid smoke of which mingles with that of the pipes. Some young lambs and a colt are tied in a corner; a pile of mattresses and coverings wait to serve for bedding at night. Some women in red rags and tatters, these likewise of a repulsive slovenliness, go and come, taking orders and grumbling. A little boy approaches and gazes at me with his two big, beautiful, dusky eyes. Most fortunately, being Christian, I am impure and consequently exempt from the grasp of the hand of the men and from the caresses of the child. The dogs also are impure, so that perhaps through dread of filthiness or respect for beliefs they dare not enter the kibitka, and stay at the door.

After the customary salutations these people conversed on subjects of interest to them—their horses, colts, money; above all, of silver, but also of wool from their sheep, for which they did not obtain as much as the value of a dog of one of the Armenian Christians come to the village. This sale kept them a little too near Astrabad, which made them fear that the governor might hear of their indif-

ferent conversation on the subject of taxes. Moreover, on the least alarm they prepared to withdraw toward the Atrek River, so as not to pay the Adjémis (Persians). Then they talked about one of their young men who recently had been accused of stealing three horses from a Persian camp and commended his valor.

Thinking that I had stayed long enough in this dirty, infected place to pay honor to my hosts, I entered the tent prepared for my use. Late in the evening, a great Turkoman brought a large copper tray covered with a cloth not too dirty. It is my dinner that my host offers me, some curd and cheese, a ragout of chicken with saffron, some rice, some bread, and a roast goose. Unfortunately, they had neglected to dress the goose.

Of the same race as the Turkomans,[1] the Shah-Sévends[2] are the Tartars inhabiting the valley of Kara Su, tributary to the Araxes. Their territory lies between the Russian frontier of Leukoran and Kara Dagh.[3] Many years ago they revolted against Persian authority, pillaged the neighboring villages and the valley, and were obedient only to their chiefs. During the 25 years that I traveled in Persia, it had not been possible for me to enter their country and the only time that I had had the privilege of meeting any of their chiefs was in the streets of Ardebil, when they passed by in chains. But since that time the chiefs have settled their difficulties by making some presents to the authorities at Taurus, principally to the crown prince, who later occupied the throne under the name of Mehmet Shah, and to-day, returned home, they have resumed their life of brigands and wage war only the more fiercely against Persian troops.

Although of nomad origin, like all the Tartars of Transcaucasia and Azerbijan, they have followed the example of their congeners and built a number of villages in their valley, living in them in winter, and as spring opens seeking the pastures of the mountains with their herds. They are very contented seigniors, for they levy on the royal authorities, rob their neighbors, and live as largely as possible under the feudal system of their ancestors.

Among them there are many tribes and consequently many chiefs; while each of the tribes is divided into clans which, as in early times, furnish the chiefs with subsidies and men, so that they may be able to

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[1] These Turks have lived in the country since the invasions of the Middle Ages. It is probable that they came from the north through Derbend, Baku, and the Magan steppe, and that they belonged to the same immigration as the Tartars of Kazan and the Crimea, when the population of Azerbijan seems to have come by Chah-Toud and Teheran skirting along by Turkomania the southern foot of Elburz on the plateau.

[2] Shah-Sévends; from Shah, King; and Sermek-Aimer, friends of the King.

[3] This valley of Kara Su is the only way open in the north of Persia by which invasions coming from the north by the defiles of Derbend could have been introduced on the Iranian plateau. To the west are the high mountains of Kara Dagh, to the east the peaks of Talish, extensions of Elburz. Only the valley of the Kara Su is open.

sustain the interests of the tribe. It is estimated that there are from 30,000 to 40,000 of these " favorites of the King."

In advancing toward the west you cease to see the Turks, and little by little the Kurd element predominates in the villages, for the open regions are left behind to enter the mountain gorges, and it is only in the flat regions suitable for maneuvers of their cavalry that the men of the steppes are established. The hilly regions favor ambuscades, and the Tartars have no taste for a kind of combat that does not permit an attack from afar, free from much danger, and then to escape at full speed of their horses when a hand-to-hand fight becomes inevitable. The Persians themselves do not at all like expeditions into the mountains, and the defiles inspire them with such great terror that the Kurds have been able to preserve their full independence.

All these peoples, moreover, Persians, Turks, Kurds, Lúurs, etc., are the most perfect cowards. War for them consists in pillage; they assassinate, but they do not come to blows. The Turks themselves, who in other countries under powerful chiefs show such great military qualities, are wretched soldiers under the Persian system.

In my many journeys I am often placed in perilous situations. On nearly every journey I have been deserted by all my native personnel or else forced to go on with much reduced force rather than to be left alone. My men would tell me " I fear," and I could not understand this cowardice on the part of men armed and strong enough for defense. But in studying them and talking with them I finally comprehended their attitude. Fear among these people, who had never been taught courage, is a nervous sensation comparable to vertigo. Fear is not dishonorable in them any more than vertigo is in us, and none of them ever having been taught to banish fear by the will, nor made to understand that on courage depends the life and prosperity of the individual and the community, they give way to fear and frankly confess it. A Persian general who came one day to tell me of a fight between some nomads ended his story with this conclusion: " No; never have I had such fear of my life."

At the foot of Mount Ararat, in the angle formed by the two frontiers of Russia and Turkey, lies the Territory of Maku. The khans are Kurd nobles. Their capital, Maku, is an agglomeration built beneath an immense rock shelter and of most curious appearance. This very peculiar site has probably always been inhabited ever since man came into these mountains. You see there numerous traces of a small Armenian village, and it is said that cuneiform inscriptions are found which are probably written in an extinct language.[1]

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[1] This country during the Assyrian epoch was part of the Kingdom of Urartu (or de Van) where they spoke a special language, some texts of which are found near Gheuk-tchai (blue lake, Goktcha of the Russians) near Etchmiadzin and as far as Mukri in Turkestan.

In summer the villagers and townsmen go to the mountains with their herds. The khan is established in a cool place, where he receives with the most perfect affability, for he is a very politic man through his contact with the Russians.

In winter there comes to live at Maku not only the khan, but a crowd of his friends, who, like himself, carry the title of khans. They own a good number of villages, and, with their chief, hold a small court. It is the khan who treats with the Persian Government for all his family on questions of rent, and his friends are heard with him. It is likewise the khan who in his domains and those of his family levies the troops necessary for guarding the frontiers on the Turkish side and to prevent the Kurds of the vicinity of Bayazid from making raids on his territory. One of his family generally commands this small army, but when circumstances are urgent the khan himself conducts the operations.

The Persian Government has always considered the khans of Maku as the valuable guardians of its frontiers. Thus, in the twentieth century, and in one of the Provinces most submissive to the royal administration, Azerbijan, we see this khannat enjoy all the prerogatives of feudalism, have his vassals, his troops, and administer them himself, with the consent of the Persian Government.

But this seignoir who, often crossing the Araxes River, takes the road for Tiflis, very rarely goes to Taurus. Who knows, after all, whether the friendship of the viceroy of Azerbijan will not become so pressing that, held by the most cordial hospitality, he will never revere his small dependencies? He prefers now to maintain from afar equally valuable relations.

It is quite otherwise among certain Kurd tribes of Mukri. Those who have preserved most of their liberties attain it only against the will of the kings of Persia. In many cases the Persians have punished them with the greatest severity.

I shall not speak of the khans and aghas of Gherrus, of the valleys of Djaghatu and Tatau, of those of Sakkis, of Bahnech, of Saudj-Bulaq.[1] They are to-day just as the provincial seigniors were in France during the reigns of Louis XV and Louis XVI; that is, great land proprietors deprived of all their feudal rights. I shall speak only of two small tribes, those of the Mâmêches and the Meñghurs, irreconcilable enemies inhabiting the valley of Kialvi,[2] tributary of the Tigris, on the frontiers of Turkey, who are permitted to support themselves and to live according to the customs of their fathers.

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[1] These districts formed part formerly of the Madai country where the Assyrians often came on expeditions. The cuneiform texts teach us that they found there a great many small principalities. The country was then in the same social conditions as at the present day.

[2] Le zab of cuneiform texts.

These tribes have at their head some aghas and are subdivided into a goodly number of clans, each controlled by more or less remote relatives of the chiefs. They could each furnish but a few hundred armed men. The winter they spend in the villages, in the summer they live in their black tents. During the cool season they stay in the valley and take care of their fields; when the heat comes they betake themselves to the mountains with their herds.

In the village the house of the chief is the largest and can be distinguished from afar; at the camp his tent exceeds all the neighboring ones in height. It is covered with black mohair cloth encircled with embroidered plants (tchikhs) and is divided into three rooms—the center one, open on one side, is the konak, or reception room; the rooms on the right and left side are closed, one is the men's apartment, the other the andérun, or harem, where the women and young children stay. The cooking is done in the andérun, and in the men's room, or the konak, they eat their meals. Before the tents the horses are tied, always saddled.

Each group of habitations in the mountains has its great tent in the center of the camp, but much smaller than that of the agha, and the group of the chief and of his relatives occupies the center of these small villages. In the tent of the agha are found the silver arms, scrolls, all the most precious possessions of the tribe, as well as means of defense against attack.

All the cattle of the tribe are brought together for pasturage and the men form a strong guard around it; but when evening comes each village of tents drives home its herd and guards it there during the night. A real pack of enormous dogs watches on the outskirts, and at the least alarm all the Kurds are afoot, gun in hand.

While the herds are in the mountains, a certain number of men stay in the villages of the valley to watch the crop of wheat and to prevent an enemy from burning it. At harvest time a good number of men come down from the mountain.

The cultivated lands are parceled out among the various subordinate chiefs, the agha reserving his part, and each subchief allots shares among the rayats, all the parcels being given pro rata according to the number of field hands at the disposal of each clan.

In Persia, down to recent years, theoretically there was no real ownership of land. All, lands and men, belonged to the King; but in practice the great benevolence of the sovereign allows the use of lands by certain persons who have paid rental for it. This unusual method of proprietorship is passed on from great to small in the customs of the entire population. In such manner, among the Kurds, for example, the agha is supposed to own everything and only temporarily delegates his rights. But if the King or the agha wished to

take possession of these lands there would be a general levy of arms, custom having more force than the law.

In Kurdistan questions relating to cultivated lands are regulated by secular customs and seldom contested; but in the case of pastures the limits are uncertain, and often the herds in crossing a stream have aroused bloody disputes between two neighboring tribes.

In the valley a small river separates the territory of the Mâmêches from that of the Meñghurs. When I traveled there in 1890, I noticed on the right and left the ruins of many villages situated about 200, 500, and 1,000 meters from this boundary river, while the inhabited villages were nearly 2 kilometers distant. This disposition attracted my notice, and asking persons about it I quickly learned the reason why these villages had been abandoned. The interests of two tribes, in war for some centuries, are the more secure the nearer they are to the frontier, the villages playing the rôle of watch posts. The Mâmêches and Meñghurs had therefore built as close as possible to the stream, but beyond the range of the arrows drawn on the opposite side of the river. But firearms one fine day made their appearance among the nomads and the projectiles killed enemies in the houses. They were then obliged to widen the neutral zone and to place the frontier posts farther away; then, the range of arms increasing, they moved to a still greater distance. To-day the Kurds consider that about 2 kilometers interval gives shelter from the enemy's bullets.

They told me many incidents about the war between the Mâmêches and Meñghurs, and listening with pleasure to all these stories of the past I thought that these people should not be so stupid as to kill one another because of troubles reaching back for centuries, maybe thousands of years, the origin of which they would necessarily be ignorant. Now, one evening as I talked of the Mâmêches in the tent of the agha, I saw a man enter with his white cotton trousers covered with blood. He was a chief who had avenged the honor of his tribe; he had killed a Meñghur shepherd without defense. It would not be difficult to find other Mâmêches and other Meñghurs in the part of Kurdistan extending from the valley of Revanduz as far as Kermanshah and Zohab. All the districts shelter some small tribes of this people, more or less savage, more or less pillagers, and living outside the world under the direction of their hereditary chiefs; but they all look alike and differ only in the dialects in which they converse.

The south of Kurdistan and Luristan are divided among a great number of khans, who, without being absolutely free, financially, enjoy none the less all the privileges of feudalism. These are the khans of Kialhurs, of Kérind, of Djâfis, of Ghilan, of Avroman, etc. But I shall not delay to speak of these, but will come at

once to the tribes the most free in all Persia, to those inhabiting southern Luristan toward the Ab-é-Diz River, between Khoramabad and the Susiana (Khuzistan) plain on one side, and on the other side between the frontiers of the Bakhtiyari and the eastern branch of the Dirfoul River.

It is in this region that in summer dwell the Seghvends, Direkvends, Bairanvends, and Hissavends. It is there between the Ab-é-Diz River and the Madian Rud that they sow their wheat; then when cold weather begins to be felt, they go by short journeys toward the valley of the Séin-Méré River [1] to reach Arabistan and eastern Pusht-i-Kuh.

In these Seghvend tribes there are many khans, but only one high chief. The others, who are his counselors and his vassals, all belong to his family. The high chief represents the elder branch and controls the most rayats and the largest herds. The others come next, being the richer and more esteemed, the nearer their relationship to the khan. Everything is done with common consent—the farming, the changing of pastures, the choice of place for the camp, the plundering of a weaker neighboring tribe or of a caravan crossing the country—and it is with common consent also that they refuse to pay rent to the King, when they importune the governor of the Province in his city, when they rob officials on the road and even entire regiments in the course of the journey.

I have held very close and cordial relations with the Seghvends, for each year they come with their herds as far as Susa, and I have employed hundreds of them as workmen during the last 15 years.

It is a very interesting sight when ten or twelve thousand nomads arrive on our plains pushing before them forty or fifty thousand head of cattle. The invasion of the Huns in western Europe must have presented the same aspect as this crowd spread out under the walls of our château. It is a wave of animals loaded or free, of men on horseback or foot, of women carrying their little children on their backs, leading others by the hand, loaded with cooking utensils, with spinning wheel or loom. Sheep, cows, horses, donkeys, men and women, children, and dogs make a frightful sound to hear, and the noise increases as the torrent ebbs and flows, and soon there is only a roaring wave. On the right, the left, some groups stop, the cattle and the mules are unburdened and the tents are set up. Some blue fumes sifted from the hair of the tent cloths spread out in long lines pushed by the breeze. In an instant all the brushwood of the country is cut to make pens for sheep, setting for the tents, for a great heap to feed the fires. Then the herds are spread out and cover the plain, while the men circle among them guarding them.

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[1] This river bears three names: Gamas in its upper part, Kerkhah in its middle portion, and Séin-Méré when it passes into the plain of Arabistan.

watching the horizon, while the women go for wood and water, or wash their miserable rags.

In the midst of the groups of tents you easily distinguish the home of the chiefs. Some horsemen emerging from it go and come from one group to another, making endless visits on business.

In a few days all the herbage of the region is eaten up. Then the tents are struck and the camps reset some miles away; there are left in the plain only the yellow spots on the site of the camps, piles of cut wood, burned sticks marking the fire places, some wooden feeding troughs, where the horses and mares of the rich ones had eaten grain brought from the mountain.

But there are complaints from the neighboring Arabs about water questions or thefts committed by the Seghvends. They dispute without agreement; and shortly shots start in the plain. From one side and the other buffaloes and sheep are stolen; soon the fight becomes general, and all night you hear the fusillade mingled with the barking of dogs, from time to time firearms flash in the darkness, now and then there are some wounded and dead. But these incidents are of hardly any consequence, for one day the chief of a neighboring tribe brought me to attend his brother and two of his men severely injured, and his mare whose neck was pierced by a bullet. The fate of this beast concerned him much more than that of the men. "And my mare," he kept saying to me incessantly, while I thought of the wounds of his brother.

The rumor spread that the governor was sending some troops to collect the taxes. In an instant hostilities ceased, the Arabs retired towards Lower Kerkhah. The Seghvends struck their tents, and crossing the ford of the river came into another Province to seek pastures on the frontiers of Mesopotamia far enough from Persian authorities to insure freedom from taxes which they do not wish to pay.

There they ran their heads against Arab tribes of the Béni-Lams, Bairanvends, and Direkvends, their congeners, and the shots flew again. Finally, hot weather returning, they quit the dry plains, and slowly as they had come retraced the road to Khormabad and the summer pastures.

The men carry on war, are occupied with their cattle and horses, knit their woolen socks, and smoke. The women are employed in household cares, carry water and wood, prepare the meals, wash their meager possessions of family linen. Between times they spin the wool, weave cloth for the men's clothing, prepare dye for making rugs, a work in which they excel, weave the great haircloth coverings for the tents, make the horsehair ropes, and doing this watch their children, cook the bread, make the curd, churn the butter, etc.

The tribe itself produces the greater part of the necessaries of life. Wheat, barley, and tobacco are raised in summer in the mountains, and the cattle furnish meat, cheese, milk, curd, whey, woolens, carpets, tent cloths, ropes, etc. So that the only articles the nomads must procure in the cities are arms, ammunition, white and red cotton-ades worn by the men and women, salt, sugar, tea, cooking utensils, and other manufactured articles. The pecuniary resources of the tribe comes from the sale of wool and hair, rugs and felts, horses and cattle; but they sell few of their herds which are used, on the contrary, to increase them. Though these men possess all that is indispen-sible for life, they are very poor in actual money, so that the posses-sion of a few krans (about 10 cents) is their constant thought.

The feudal customs of these tribes are reflected to some extent in the way in which the fellahs labor in our workshops; each shop equipped with 50 men is headed by a Ser Kar (foreman) who, although paid, would receive from his workmen 1 day's wages out of every 10. Each 10 days also another day's wages is assigned to the khan of whom these men are dependents and who furnishes them for our employ. In fact these fellahs give 20 per cent of their salary to their chiefs. I was forced to abolish this tithe and forbid it. But since such things are done in secret they continued as if I had said nothing. To-day I close my eyes.

The Seghvends, through their contact with the cities of Arabistan, and also on account of their presence for 15 years in the workshops of Susa, are to-day much more civilized than their congeners, the Direkvends and Bairanvends, who have their winter quarters in the valley of the Séin-Méré. These tribes, administered the same as the Seghvends, have been exempt from the law for many years. They are bandits, robbing caravans and stealing from their neighbors who are nomads like themselves; they are therefore looked upon with disfavor throughout Luristan. One day on the route between Khoramabad and Dizful they robbed an entire Persian regiment, the colonel at its head, without doing other harm to any one; but they took everything—arms, ammunition, provisions, baggage, uniforms, horses, and mules—and little was their need for them, for it was only in the costume of Apollo Belvedere that this valiant regiment, with colonel ahead, made its triumphal entry into the city of Dizful, to which it was assigned as garrison.

This unfortunate pleasantry, however, led the governor of Lur-istan, a prince of royal blood, residing at Kermanushah, to decide to severely punish the miscreants; but, since it costs to levy troops for such a task, he charged the other khans heavily and required the Vahli of Pusht-i-Kuh to make these insolents " tchapou " (depriv-ing them of everything save life). As may well be believed, the

war drags along and the Direkvends, after having bribed the Seghvend chiefs, secure through gifts, freedom from disturbance by the Vahli of Pusht-i-Kuh. I was in these mountains when the presents were received, which included a large sum of money, some mares, some young girls, the handsomest of the tribe of Direkvends, some arms, and some rugs.

Were not these the presents that Asurbanipal received from petty kings who aroused his wrath?

The Vahli took time for reflection, and after three days' seclusion in his harem withdrew his troops.

These Direkvends are very deeply in debt. The tribe I have known the longest is that of a certain Aslan-Khan living between the two branches of the river Ab-é-Diz in a region which is a veritable chaos of rugged mountains. In summer this personage with his men dwelt in the mountains near the plateau, bordered on this side by high cliffs; but when cold weather begins they leave by paths cut in the balcony under the precipices and gain the warm valleys more to the south. There they have their villages, their fields of rice, grain, tobacco, and vegetables. The soil and their herds yield full abundance. Within their domain are mines of salt and bitumen, and immense forests of evergreen oak; and in the valleys all kinds of fruits except the orange. They never need go to the cities, from which they receive arms and ammunition from time to time. Their blue cotton costumes of material made and woven by themselves are exactly like those of Persians of Achæmenian times, their headdress is the same; their beards and hair are of the same cut. Not a thing has changed in that country since Darius ruled the Persians, only in their weapons do these men differ from their ancestors. In their inaccessible refuge they have braved all kings; invasions, conquests, have not touched them, and if they have become Mussulmans it is only because their neighbors having adopted that religion they have thought it more useful for the preservation of their liberty to follow the general movement. Elsewhere in these mountains there is very little concern about religious beliefs and usages; the women do not veil the face, and in general this is to the great loss of those who see them.

The country inhabited by this tribe is admirably adapted to the preservation of customs. It is a vast triangle bounded on the north by mountains very difficult of access, and on the sides by rapid rivers flowing through canyons many hundreds of meters deep. The neighbors to the south and southeast are the Bakhtiyari, those to the northwest and west are the Seghvends. But these people have no relations with their congeners on the right or the left; they are not even known by name in the neighboring tribes. They are the most isolated beings that you can see on a continent. In 1891 I attempted

to visit this tribe, but its chief, Aslan Khan (The lion chief), dissuaded me in very convincing terms. Never had any man foreign to his tribe trod the soil of his little domain and he held guard over its secrets.

"Thou knowest Mesched-i-Nassr,"[1] he said to me. "Well, go and find him and tell him that he is a Péder Soukhte,[2] because he eats money, and that if he wants to get any from me he must make the search himself."

During this conversation the followers of this prince stole the roasting spits from my cook.

After having discussed some of the subseigniors, we will speak of the principal ones, some real feudal princes, who, though Persians of the twentieth century, are the same as were the dukes of Burgundy or Brittany in France at the time of Louis XI. There are a few of them elsewhere, the principal ones are the Vahli of Pusht-i-Kuh, that of Bakhtiyari and the Sheik of Arabistan. The first two are from old Iranian stock; the third is a genuine Arab Melek, a dignified successor of the sovereign princes of Characène, a country of which he owns the greater part.

The Vahlis of Pusht-i-Kuh, that is, "back of the mountain," or "outer mountain," have been masters for some centuries of their principality which reaches to the confines of Mesopotamia, from the interior by a rapid river, the Séin-Méré, and a high chain of mountains. Kebir Kuh (Mount Kebir) opens at only a few places and like a wall protects the territories of the Vahli against incursions. These people, few in number, thus pass their lives almost exclusively on the slope of Mesopotamia. In summer snow and fresh pasturage are found at Mount Kebir. In the plain below grow the date, the orange, and the pomegranate. A day's journey by horse brings one from snow to the torrid heat of Mesopotamia; but it takes about six days to cross this principality from north to south. Numerous streams descend from Mount Kebir toward the Tigris, but without reaching it, for the fields take possession of the waters and by a thousand canals spread them on the lands.

Pusht-i-Kuh is situated northwest of the roads leading from Arabistan into Iran, properly speaking,[3] across Luristan and the countries of the Bakhtiyari. This country lies south of the route from Bagdad to Hamaden,[4] through Kermanshah, and its position between two important routes of travel, as well as its frontier pro-

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[1] Nassr ed Din Shah who having made the pilgrimage of Mesched had right to the title of Meschedi.

[2] "Son of a scorched father," the highest insult of Persians.

[3] In olden times the royal route from Persepolis to Ctésiphon traversed the eastern part of Pusht-i-Kuh, and one still sees traces of it in the ruins of the Sassanide-de-Pâ-i-Poul bridge over the Kerkhah, from the place called Bayât to the frontiers of Turkey.

[4] This road was the one followed by the royal route from Babylon to Ecbatana (Hamaden); It passed through the gorges of Zagros, where numerous traces are found.

tected by nature, enabled it to preserve its independence both in ancient [1] times and in our day.

By the Kings of Persia, who have never placed any heavy burden on them, these people are considered as frontier guardians and have been favored with light taxation, the right to maintain an independent army, and have been granted many other privileges of less importance. At times they are called upon to furnish auxiliary troops for the King, and, as was formerly done by the vassals of France, they serve by the side of the sovereign or of their marshals, commanding their own forces, or at least are given command; for the vahli leaves his domains as little as possible, either because he dreads finding a competitor on his return or through fear of being more or less graciously detained as a hostage at court, to be released only at the cost of ruinous gifts.

The vahli of Pusht-i-Kuh can put in the field from 1,500 to 2,000 men, infantry and cavalry. These soldiers arm, mount, and uniform themselves; but while on a campaign they are allowed rations, money, or partial exemption from taxes. The Government is not concerned with these details, but the vahli meets war expenses from his own resources, even when he carries on a campaign by order of the king. A reduction of tribute indemnifies him in part for his expenditures.

I knew the aged vahli, Hussein Kuli Khan, very well; he was a big, powerful man, resembling portraits on certain drachmas of the Arsacid King Mithridates II. He was very hospitable, although he had the reputation of being very firm and often harsh, which, however, brought him the esteem and respect of all.[2]

His court was made up of an administrative officer; two or three ambassadors,[3] men of intelligence whom he sent on special missions; one or two letter writers; a mullah (expounder of the law and dogmas of Islam) whom otherwise he never saw; his brother, chief of his cavalry, carrying the title of colonel; a certain number of Khans at the head of his infantry; and a Jew who never left him and whose only duty was to keep busy making date brandy which this excellent vahli Mussulman drank in prodigious quantity.

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[1] The Chaldean emperors without doubt made some campaigns in these mountains, and I think that the tablet of Naram-Sin (Musée du Louvre, excavations of Susa) represents an expedition of that prince in the country which to-day forms part of Pusht-i-Kuh.

[2] In the East only those are respected who inspire fear. Kindness is always considered as a weakness and is taken advantage of at once unless some exhibition of firmness recalls the sense of duty. Many governors have been driven out because they were too mild.

[3] One of these ambassadors, Kaid Khani Khan, a very intelligent young man, chief of a tribe which he had organized himself, who died only a short time ago, had on one occasion been sent in an embassy to the chief of the Beni-Lams. He finished his mission; then taking the road for his return, met a patrol of Turkish soldiers, who found nothing better to do than to make " tchapou "—that is, to take away his arms, ammunition, and baggage. This ambassador under the privileges of diplomacy had some thoughts quite special, but otherwise this incident created no impression other than to make the vahli laugh to tears.

Pusht-i-Kuh is divided into districts parceled out among the several tribes. Each tribe has its warm lands and its cold lands, administered by a chief who as a rule does not belong to the family of the vahli, but is chosen by him, some descendant of old servants of his household.

In all Pusht-i-Kuh there is not a single permanent village, the entire life of every one being passed in tents on account of the very mild climate of the country.

The vahli owns a winter residence near the Turkish frontier (Husseinieh). The house, built in the midst of date and orange groves, is adorned with numerous representations of massacres of wild goats,[1] a decoration whose origin dates back probably to the time of the Elamite Kings of Susa.[2] Another residence, much larger and built in the mountain, was intended for summer sojourns. But it is always hot at Pusht-i-Kuh; and since they carefully choose their encampments for varied seasons, they obtain an equal temperature during the 12 months of the year. Thus Hussein Kuli Kahn, always living in a tent, his two houses fell into ruins.

I have on many occasions passed entire months at Pusht-i-Kuh and often some weeks near the home[3] (Husseinâbâd) of this old man, who with good reason considered me as his friend. "What a misfortune that you can not be a Mussulman," said he to me one day, and there was in this remark the highest compliment, the most sincere that could come from the mouth of a Mohammedan.

Never did Hussein Kuli Kahn come out of his harem before midday. Then he mounted a horse and often invited me to accompany him on his rides. The little troop included, besides ourselves, the minister of the vahli, his sons, some cavalry, and a few servants, one of whom carried the kalian[4] hung on the flanks of his horse, as well as the necessary burning brasier, while another servant had in saddlebags the samovar[5] tea, sugar, and all the apparatus for making Persian tea.

We rode along for about an hour, then rested in the shade to take tea, and the vahli began to dispose of some current business matters. The minister read the letters recently received, Hussein Kuli Khan dictated the replies, and taking from his pocket a small cloth bag drew from it his seal,[6] which the minister immediately carefully

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[1] The representation of the wild goat played an important rôle in Susian decorative art from the most ancient times down to the Assyrian conquest.

[2] The goat lives in great numbers in a wild state on Mount Kébir.

[3] The amalah is the camp, the residence of the chief of the tribe.

[4] What the Turks call "naigileh," more common than the Persian name.

[5] The use of the samovar, which the Russians got from the Tartars, has spread throughout Persia, Mesopotamia, and a great part of Turkey, as well in the homes of the nomads among the sedentary population.

[6] Among orientals the seal is equivalent to the signature; it is therefore preserved with the greatest care.

affixed either below or on the back[1] of the written page. This seal was then returned to the vahli's pocket.

When a difficult case was presented, they discussed it; each gave his opinion, even the servant who had served the tea or passed the kalian. If one of the opinions pleased the vahli, he adopted it and dictated his reply accordingly; if not, he opened the Koran at any page whatever and according to the word at the angle of the first page, that on the right side, consequently, he settled the business or else postponed it till the morrow, the drawing by lot having convinced him that this particular day was not propitious for settling such an affair. Or else, counting a certain number of beads of his rosary, he would toss up for a decision.

St. Louis judging under his oak tree was certainly not grander than this new incarnation of Mithridates II dispensing justice in the open air, taking for his counselors all those who surrounded him, listening to all complaints, all demands, all requests, familiarly conversing with the most humble of his rayats or serfs. This sight gave me really a broad idea of primitive institutions among the Iranian peoples. The audience ended, Hussein Kuli Khan felt the need of quenching his thirst, and a servant approaching very ceremoniously offered him a large silver cup holding at least a pint of liquid, which the vahli emptied at one draught: it was brandy.

We returned from the ride; the vahli talked no more, retired into his tent, and slept until evening; then he dined with his wives, again took some brandy, and showed no more signs of life until the next day.

When I arrived at Pusht-i-Kuh, Hussein Kuli Kahn promptly sent a troop of cavalry to meet me, its military band equipped with flute and tambourine fastened at the saddlebows. It was in this parade, in the midst of mares that made my horse rear, that I was conducted to the site chosen for my camp. Scarcely had I put foot to the ground when a crowd of domestics arrived, the chief ahead, carrying some plates loaded with fruits and other refreshments. Then the visits began. Hussein Kuli Kahn first sent his sons or his minister to learn the state of my health, and, about an hour later, having made inquiry of the vahli through my chief servant as to what hour he could conveniently receive me, I went to his tent and remained there about 15 minutes. An hour later, as the agreement willed, Hussein Kuli Kahn came in his turn to my camp not without requesting an hour when I would repeat my visit. Then I made some presents of money to all his servants, each receiving according to

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[1] The king places his seal at the top of his firmans and at the bottom of his letters; on a special writing to his equal he puts it on the back of the paper facing the last word he wrote; to place it at the foot of the written page would indicate to the receiver that he was considered as his servant.

his position near his master, and the vahli charged his minister to do the same to my attendants.

I then sent to the vahli by my head servant the presents brought from Paris for his sake, chiefly some arms inlaid with gold or silver. The same day or the next morning he sent to me by his head equerry a very fine horse.

These ceremonies finished, etiquette was ended, and we afterwards met only in the most familiar manner. His sons, his minister, often came to see me, and I made it a point always to return their visits. I talked with them about a thousand things of the country. I asked them about their habits, the people, the politics of the tribes, and they asked me details about Europe. In 1896 Hussein Kuli Kahn gave me for a guide in his country an old equerry long in his service. In 1904 I asked to see this man. He had become a paralyzed old man, so that they had to carry him to my camp.

They talked much at Pusht-i-Kuh of the recollection that Europeans preserve of services that have been rendered them, while among the nomads a man is forgotten from the day when there is nothing more to expect from him.

On the death of Hussein Kuli Kahn his elder son, the conqueror of the Direkvends, of whom we spoke above, succeeded him by right, but the younger son for many years would not agree to serve under the authority of his brother. He withdrew to his domain of Houleilan [1] and went to war against the new vahli, as at the time when the sons of one of the Arsacidæ disputed the throne after his death. Finally, the two brothers were reconciled, peace was restored in Pusht-i-Kuh, and, as formerly, all was ruled there according to feudal traditions.

Other Iranian high seigniors are the vahlis of the Bakhtiyari, whose tribes occupy all the country between Ispahan and Shuster, between the river Ab-é-Diz and the vicinity of Bender Buchir. They are the principal vassals of the kings of Persia. The organization of their tribes is the same as at Pusht-i-Kuh, except that the Bakhtiyari army can put in the field from fifteen to twenty thousand men; and the khans as well as the vahlis of this country, coming in frequent contact with the Persians of Ispahan and with Europeans, are much more intelligent than the seigniors of Luristan. Many go to Europe, some speak English or French, which, however, does not hinder them from adhering just as closely as my friends of Pusht-i-Kuh to the old feudal institutions.

The tribes of Bakhtiyari are to-day the soul of Persia, because they are powerful and well governed. To be sure, there are some frac-

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[1] A district in the valley of the Séin-Méré to the north of Pusht-i-Kuh which Hussein Kuli Khan had bought for his younger son, foreseeing that his succession involved some difficulties between his children.

tions of this people whose morals and instincts are still very barbarous; it would be surprising not to meet such a class in so vast a territory. But in general there reigns among them a strict discipline, which singularly contrasts with what we found in Kurdistan and Luristan.

These countries, it seems, have always been very nearly independent. All that can be positively stated, however, is that the tribes which live there to-day occupied the country under the Achæmenidæ, but nothing hinders the thought.

The royal route which connected Persepolis with Babylon crossed the country now occupied by the Bakhtiyari, and we know that the Great King himself paid a tax to tribes of these mountains when he passed over their lands. The khans were even then seignors of much importance. We made a short visit to a high Arab seignior, El Mohammerah, a powerful Gharal chief. We found him in his palace built on the bank of the Persian river Chatt-El-Arab, in honor of Mohammerah, below Basrah. He is an amiable man, keen eyed, intelligent, very polite. He keeps abreast of all that occurs both in Europe and in Luristan, at Teheran, and among all the tribes of Mesopotamia.

Sheik Ghazal is one of the richest land proprietors. He personally owns immense domains both in Persia and Turkey, and all the sheiks of Arabistan recognize his supremacy, which is in a measure felt likewise by the armies. He is a veritable Malkim Malek, controlling an important treasury, a numerous army, steamboats—in fact, everything that can bring wealth, intelligence, and power. English boats salute him with cannon, and from ashore he returns the salute with his own artillery. No one would dare touch the Sheik Ghazal, who smiles at revolutions and at the fall of sovereigns. He is king in fact—what cares he for those who are such only in name?

As one may judge from the preceding pages, the feudal seigniors still play an extremely important rôle in the Persian Empire. Their power is great, for the spirit of nearly the entire nation still rests in feudalism.

If we leave the domains of the seigniors and enter the cities in the very heart of Persia, we find there among the merchants and the artisans the same kinds of corporations and all the institutions that prevailed in France in the Middle Ages—the tithe from gain for the clergy, immunity of beneficiaries of the church, and many other privileges which formerly existed among us.

Persia to-day represents what France was before Richelieu, that period when for the security of the Crown it was necessary to achieve the work of Louis XI, to demantle the great forests, to crush the remains of feudalism.

This feudalism is always very powerful in Iran; it has deep roots. That is what we wish to show in this study. It would have been easy to cite a much greater number of examples, to conduct the reader to the homes of hundreds of begs, aghas, or khans; but we have judged it futile to enter into such numerous details. A few types are enough to show how Persian feudalism was born, how it traversed the various phases of life of the empire on which it depends and, finally. how it is still maintained in our day. You will pardon me for having cited some personal incidents. It has been done to offer some proof of my story, and most of these incidents are of a nature to enable the reader to judge more clearly of the mentality of the people discussed.

ILE ROUSSE (CORSE), *February 12, 1912.*

SHINTOISM AND ITS SIGNIFICANCE.[1]

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1. HISTORICAL SKETCH.

In mythical antiquity when as yet nature and mankind, mankind and the gods were viewed as unseparated, a people landed on the island of Kiushu, in the southwest part of Japan. Scholars differ concerning the racial affinity of that people; some would assign it to the Malay race, others to the Mongol, while still others to the Phœnician or even the Greco-Roman race.

This people seems to have been superior to all others who had previously settled in Japan. It was at all events conscious of its power and imbued with the divine right to rule Japan. Ama-terasu, "the Heaven-shining one," the fair, mild, bright, victorious sun goddess, was its diety, and of whom it was the offspring. According to the Japanese myth this sun goddess sent her offspring from the celestial realm to the land of Japan there to establish order and dominion: "The land of Japan, the Middle Kingdom, the rich rice field is the land where my offspring shall rule." This was her word and command.

But somewhat prior to this people another race, likewise powerful and civilized, had settled, not in the southwestern island, but in the northwestern part of the principal island of Japan, in the coast land of the Japanese Sea—in Idzumo. This people rapidly spread and, at the time of the arrival of the children of the Sun, had nearly subjected the whole of the principal island with the exception of its northeastern portion. It is quite certain that this people, whom we shall here call the "Idzumo," was closely related to the Koreans, and on that account alone was it superior to numerous other peoples. The affinity of the Idzumo with the Mongols can not be established with certainty, but it is probably very close. Whether it belongs to the same race as the Sun offspring is still an open question.

The disposition and the character of both peoples are different: there is especially noticeable a great difference in their religious con-

ceptions. The tribal deity of the Sun offspring, as already indicated, is the sun; the princes very frequently bear names in which the word " sun " (Japanese, *Hi*) is contained. The disposition of this people is serene, bright, one might say tropical in the good sense. The character is indescribeably fine, brave, aristocratic.

On the other hand, the tribal deity of the Idzumo is a god of the storm, the clouds, and the sea, vehement, wrathful, and angry. The disposition of this people is somber; the character is more practical than aristocratic. Life's happiness and enjoyment were more esteemed by them than governing power and brilliant deeds of valor.

Under such conditions the Sun people found a rival in the Idzumo. The land, which was considered to be its mission and divine right to govern, it found in the control of others. With an amazing sense of its right and might, it sent a messenger to the Idzumo demanding the right of government from the rival. As might be expected, the Idzumo refused to comply. A second message was sent in vain. Thereupon the Sun people dispatched its brave general with a fleet and ordered the demand repeated. Some small skirmishes ensued. But the Idzumo were of a practical turn and eschewed the sufferings and inconveniences of war. And thus, on the condition that the Sun people allow the court of the Idzumo government to continue in its former splendor, the dominion over the land was surrendered to the Sun people.

But the island of Kiushu, where the Sun people had settled, is situated at the southwestern end of Japan, which is very inconvenient for the fortification of an empire and the subjection of the entire country. Several generations passed away in small, insignificant quarrels with the surrounding tribes. Then there arose a great and mighty movement. Prince Kan-Iware, of the Sun people, left the place of his birth, the home of his forefathers, and set out with his warriers in ships for the land of the Middle Kingdom. There he fought with various tribes; with the native, hairy Ainu as well as with the vassals of the Idzumo. The sun was his tutelary deity. He fought in the firm belief in his right and the protection of his ancestress and in the end succeeded in establishing an empire in the center of the principal island of Japan. This Kan-Iware is the first Emperor of Japan—the Emperor Jimmu. He is assumed to have founded his throne in 660 B. C.

2. DEFINITION OF SHINTO.

The word " Shinto " means the " way of the gods "—that is, the doctrine of the gods—and was coined in the sixth century A. D., when Buddhism was introduced into Japan from Korea, in contrast to " Butsudo," the way of the Buddhas. Thus, the word originally denoted the entire native religion of Japan. In the course of time

Shinto underwent a certain, if small, development; in the eighteenth century, following its renaissance, Shinto assumed a pronounced color and definite form and characteristically pure spirit. Some foreign investigators overlook this fact and include every superstition as it accumulates in popular life under the name of Shinto. By treating Shintoism in this manner one can never hope to reach its core and find its real significance. Suppose an enlightened Chinaman, educated in the positivistic Confucian philosophy, was traveling for his education in Europe, and without any knowledge of Christian theology or European philosophy and science, should merely peep into the churches and overhear people talk on the street. He would hear many a superstition and see many strange, magically conceived actions. If this Chinaman should group all these superstitions, mystical rites, and magical actions together and bestow upon them all the name of " Christianity " and on that account refuse it as a religion, would he be right? Certainly not. But that was done by a writer who with great pains collected every crude superstition in Japan and incorporated them in his work without order or system and without distinguishing between the noble and the base, the essential and the apparent, the permanent and the transitory. We shall, therefore, here try to bring out the essence, the kernel, of Shintoism, referring to the superstitions only in so far as they stand in any relation to the central part.

3. THE RELIGION OF SHINTO.

The background of Shintoism is nature religion. In this sphere there is hardly any distinction between nature and man, between man the gods. Mankind is nothing more than a part of nature and nature is but expanded mankind. Mountains, forests, rivers, and the sea, as also the sun and moon, are gods. Even the countries are the offspring of a divine pair. In the beginning there was a divine couple. Before the gods themselves were born this divine couple had brought forth the Japanese islands; the birth of the gods came afterwards. These gods are mostly nature gods—gods of the winds, the storm, rain, fire, field, fountain, etc. Man beheld a god in everything that struck his childlike, inexperienced, groping eye as strange—in everything that appeared to his helpless state as great and powerful, that in his hard struggle for existence was helpful. It was probably after a long period that man learned to distinguish between the indwelling spirit and the external object. The Japanese word for god is Kami, which merely means " above," " the above one." Thus, the chief of a small clan calls himself " a god of the land." All princes and rulers call themselves kami; that is, gods.

Already in this stage of religious development it is seen how intimately religion is connected with life, with its preservation and

expansion. Man fears the mighty phenomena of nature, but he can befriend them. The inner impulse of all living beings to preserve and increase life impelled man to draw to himself all that was helpful in nature, to embrace it, and to enter into a permanent covenant with it by means of all those sacred rites as primitive man knew them. The instinctive desire after more, the craving after the great and sublime, generated religion in mankind. Deep at the bottom of such primeval life, I believe we must look for the true psychological and at the same time the metaphysical root of religion, and, in particular, of Shintoism.

In this stage of religious development the Japanese people was found when the first emperor, Jimmu, already known to us, accomplished his splendid conquest. As has already been said, this people allied itself to the Sun goddess and called itself the offspring of that deity, and the later Japanese veneration of the emperors has its origin in this. The political change also brought about a religious revolution. The religion of the Idzumo, in which nature-worship played the foremost part, and the religion of the Sun people, in which hero-worship predominated over nature-worship, met and united. The hero-worship of the victorious ones was not able to drive out the nature-worship of the conquered people; of many reasons for this only one may be mentioned here. The successors of the great Jimmu were not strong men. They achieved neither expansion of the imperial power nor of civilization. Only after the lapse of about four centuries is an energetic emperor again on the scene, who, for the first time in the history of Japan, created a system of taxation and dug ponds for irrigating works, and started expeditions to unknown northeastern regions. Unfortunately a pestilence broke out among the men, claiming thousands of victims. In the course of centuries just elapsed the enterprising, energetic life has sunk, and with it also the religion. It is not astonishing then that we see the cause of the misfortune ascribed to the anger of the gods, particularly the gods of the subjugated Idzumo. Hence there followed a restoration of the forgotten gods. Numerous temples were erected to these gods and abundant sacrifices were offered to them. The defeated gods experienced a revival. The spirit of the conquered people avenged itself on its conquerors, becoming their spiritual rulers. A strange mixture. Even at present the two strains (sharply separable) can be discerned in Shintoism. There are two principal Shinto shrines, one at Ise, where Ama-terasu, the Sun goddess is worshipped, and the other at Idzumo, where Onamuchi, the former rival of the Sun goddess, is venerated. These two strains must be kept clearly in view for a better understanding of Shintoism. The Idzumo influence of nature-worship forms the background of the

world conception of the Shinto religion, while the influence of Ise supplies in hero-worship the active spirit of Shinto.

Shintoism survived in simple, pure form till the sixth ·century. Scarcely any distinction was made between priests and laymen, between the holy and the profane—in contrast to the Hindus and the ancient Gauls. The administration of the state, the governing was *eo ipso* religious worship. The Japanese word for " governing," *matsurigoto*, is derived from *Matsuru*, " worship." Thus among the ancient Japanese, governing and worship were identical. The religious ceremonies were consequently very simple. The greatest and most important ceremony is the purification, which takes place twice every year. The impurity and sins of the entire people are cleansed through a solemn prayer and ceremony. It recalls the Jewish scapegoat. But the ethical aspect is different; in contrast with the complex, already far advanced ethical conceptions and the rigorous idea of atonement in the later Jewish religion, here is still found a naïve, simple, and childlike ethical thought with a like simple idea of atonement. In the primitive Shinto religion uncleanliness and sin are identical conceptions.

Here we may find place for the table of the so-called heavenly sins and earthly sins from the old ritual of purification.

1. The heavenly sins:

Making of breaches in rice-field dams.

Interfering with the irrigation of rice fields.

Cranks interfering with agriculture.

Skinning of live animals backward.

Defiling ritually clean places with excrements.

2. Earthly sins:

Wounding of the body (because the blood was considered by the ancient Japanese unclean).

Desecration of a corpse.

Unusual bodily affections, such as albinism and excrescences.

Incest and sodomy.

Killing of other people's animals.

Witchcraft.

Plagues inflicted by the gods as punishment. such as snake bites, lightning stroke, etc.

This Shinto morality may be divided into three spheres:

1. Morals in relation to common property. i. e., peasants' morals.

2. Morals of the ritual.

3. The recoil from the unclean and unnatural, a genuine tabu morality. This constituted the origin of ritual morality.

We do not meet with a morality in our sense: what we find is, however, not immorality, but childlike naïveté. But it can easily

be seen that in aversion to the unclean and the abnormal, in conjunction with the ritual morality, there lies the germ of the idea of evil which, when it implies a social morality, must bring about a full development of the idea of evil and with this also the problem of conscience.

Like the morality, so the cult of Shintoism was also simple. Simplicity and cleanliness were always valued by it. Thus, its temple was and is exceedingly simple. This tendency to simplicity and cleanliness not infrequently led to conservatism. It was the constantly recurring endeavor of Shintoism to restore the so-called age of the gods, or at least to preserve as much as possible its form, manner, and custom.

The temple usually consists of two small houses. One, standing in front, is the prayer hall; the other is the sanctuary. The representation of the god usually consists of a round mirror, but often also of a sword, a jewel, etc., which, according to tradition, originated in the age of the gods. Shintoism proper knows no images. Where such are found with it, it is due to foreign influence, particularly to the Hindu and Chinese.

4. LATER FORTUNES OF SHINTO.

For a better understanding, there may be briefly mentioned in this connection some prominent facts from the history of Japan.

In the fifth century Confucianism came from Korea to Japan. The Japanese gladly adopted continental culture and the Chinese characters (letters). Confucianism came in its simple form—as a code of morals, as the science of the state, as an educational force— and comported well with Shintoism. But when in the following century Buddhism entered, likewise from Korea, affairs in Japan were different. Very soon Buddhism, by reason of its profound doctrines and the splendor of its cult, won the favor of some of the prominent courtiers. The chasm between Shintoism and Buddhism was too wide for a reconciliation between them; conflict was unavoidable. As a religion Shintoism could not compare with Buddhism. Shintoism, notwithstanding its stubborn resistance, had to give way. But the triumph of Buddhism was not a complete one. The prominent Buddhists had to stoop to declare the native gods as manifestations of the Buddha. In this manner arose the so-called "Riobu-Shinto"—that is, the mixed Shinto. This condition continued for about a thousand years, to the injury of both religions. Only as late as the beginning of the eighteenth century did Shintoism begin to exhibit signs of a renewed life. But this movement was a theoretical one, called into life by certain scholars. Their war cry was: Back to the age of the gods, away from the foreign and alien influences and culture. Not only Buddhism, but Confucianism also, was violently

attacked. One of these scholars went so far as to even assert: "The ancient Japanese had no moral theory whatever, because they were in no need of one, since their natural disposition was moral, while the naturally wicked Chinese needed a moral system." With the revival of Shintoism there appeared another powerful factor, the idea of the divine right of the imperial house. By emphasizing this idea this purely theoretical movement promoted the restoration of 1868.

5. THE SOCIOLOGICAL AND PHYSIOLOGICAL SIGNIFICANCE OF SHINTOISM.

After what has been said in the preceding pages, it must be admitted that Shintoism represents rather a low stage of religion. It has in comparison. for instance. with Judaism. experienced but a slight development. Two reasons may be assigned for this fact: First. the Japanese were on the whole little exposed to external dangers in the struggle for existence. If religion is related to the preservation and expansion of life. it may be concluded that a people living in a continuously keen and perilous struggle for existence, and none the less able not only to preserve but also to expand its life, would also in its own way raise its religion to the highest degree of development. The Jewish people present a good instance. It lived in perpetual danger, and yet by dint of its wonderful vitality it was enabled not only to preserve its existence but also to be respected as a power. On the other hand, the Japanese as a whole were beset by little danger. Thus it came to pass that Shintoism was not hardened and strengthened as Judaism was. As a second reason for the slight development of Shintoism must be considered the intruding of agnostic Confucianism and pantheistic Buddhism. The native religion and the highly developed foreign religions differed both in kind and in degree. One could not by degrees advance from Shintoism to Buddhism and Confucianism. A radical break was required. The religiously disposed minds abandoned their gods and followed the more profound and powerful teaching. Shintoism was forsaken by its best children and remained lonely and poor—a veritable mater dolorosa!

Notwithstanding this, Shintoism has survived to the present day and still exhibits a certain vitality. This is a miracle. How, one might ask, can such an apparently low form of religion continue its very existence amidst a people that has been nourished on the lofty conceptions of life and the universe of Buddhism and on the pure and elevated morals of Confucianism? Shintoism is certainly a very remarkable religious and sociological phenomenon.

But, as it has already been pointed out, Shintoism beheld in all the great, wonderful, mighty, and sublime phenomena of nature, as well as of man. its gods and worshipped them. Everything that was

something more or had something more than the usual, whether a natural thing or a human being, was worshipped as a god. Shintoism is originally the religion of the "plus" (more). It was destined to comprise in itself the preservation and expansion of the national life. As such it has its roots deep in the dark soil of the instinctive, constantly expanding life. It grew up with the national life. It is a real, germane child of the blood of the national life. Herein lies the difference between Shintoism and Judaism. The Jewish people were adopted by Jahveh, while the Japanese religion grew up from the very beginning with the people. Shintoism is no accession; it is interwoven with the life of the people. It exists among its people in a diffused, not concentrated manner. It is therefore not noticed under usual circumstances. If Shintoism has any concern at all, it is the well-being of the nation in general. Therefore only in times of danger or of a crisis in national life is Shintoism seen in a pure form and with its original vitality. Patriotism is Shintoism's own favorite child. To the Japanese patriotism means something more than it does to other peoples. Through its association with so many heroic and noble deeds and events which took place in the course of more than two millenniums patriotism gains a profound and exquisite, in short, a religious but not fanatical, significance. A few examples may illustrate this.

It was immediately after the naval battle on the Sea of Japan that I, at that time a young lieutenant, asked one of my men: "What have you been thinking of during the battle? Have you been afraid of death, or have you thought of it at all?" He answered: "No, Lieutenant, I had no thought either of life or of death, nor any fear. One thought only was strong in me, and that was to do my duty perfectly, and the only fear that I had was that I might commit an error." I observed through the simplicity of his narrative that he told what he really felt. This man saw in the service of the fatherland all that was precious. The service of the fatherland was for him the highest worship.

It was, if I remember aright, on the eve before the battle of Mukden. An adjutant was looking for Gen. Kodama, chief of staff, to whom he had a message to deliver. The adjutant went into the quarters of the general, but the latter was not in. He looked for him through the entire camp, but the general was not to be seen. Finally, the adjutant going to the rear of the camp came to the woods, and there he saw the general in the attitude of prayer, his face turned toward the setting sun. Later he was asked what he meant by all this, for he was supposed to be an educated atheist without religion. He answered simply: having done everything that in his opinion would assure victory, there remained nothing to be done but to invoke the help of the higher power.

In certain crises of life, when fate places before us an absolute demand, the fulfillment of which transcends our strength, man gathers up all his power and does what he can. He comes at the end of his strength; it does not reach further and still he hears the call of the absolute demand. The void stretches out all around him. The heavy atmosphere charged with the cold, silent, threatening fate weighs upon him. There is to be found no ladder, no wings to make use of; and yet this incessant resounding call of higher command! What remains for man to do but to cross the border line of his own strength and to invoke and appropriate unknown higher powers whether it be the cold, indifferent fate or sympathetic personal gods!

Thus we have here the belief in higher powers—religion. The call of duty is heard outside, beyond; but it does not come from the outside, but from within, from life itself. The demand has its root deep in life itself, hence its categorical imperative.

From what has been said we may draw the conclusion that so long as the nations of the world compete with one another in raising armies and building navies, so long as mere might, violence, and brutality determine the fate of a nation—so long will Shintoism survive and fulfill its task as the protecting genius of the people.

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6. SHINTOISM MUST NOT BECOME A POSITIVE RELIGION.

The influence of Shintoism on the Japanese Nation is a good one when as a force it is diffused through the life of the people, but would become fatal if it should be concentrated, fossilized as it were, and assume a definite, sharply defined form after the manner of other positive religions. Diffused, Shintoism is an active force impelling the nation forward, as an ardent love of the fatherland and of the whole. From this flow all virtues: altruism, sacrifice, loyality, etc. But concentrated it would become a contemptible chauvinism and turning its back on the whole would sink to a narrow provincialism, fettering the nation in its cultural endeavors and obstructing its onward and forward march. By this it would forfeit its mission and its life. For its lift—the longing for more—would be lost. It would thus sacrifice its most precious possession to a pitiful formula and commit a miserable suicide. It would be a corpse, loathing and noxious to the same people whose well-being was once its only concern.

THE MINOAN AND MYCENAEAN ELEMENT IN HELLENIC LIFE.[1]

By Arthur J. Evans.

[With 3 plates.]

In his concluding address to this society our late president re-
marked that he cared more for the products of the full maturity of
the Greek spirit than for its immature struggles, and this preference
for fruits over roots is likely to be shared by most classical scholars.
The prehistoric civilization of the land which afterwards became
Hellas might indeed seem far removed from the central interests of
Greek culture, and it was only with considerable hesitation that I
accepted, even for a while, the position in which the society has placed
me. Yet I imagine that my presence in this chair is due to a feeling
on its part that what may be called the embryological department has
its place among our studies.

Therefore I intend to take advantage of my position here to-day
to say something in favor of roots, and even of germs. These are
the days of origins. and what is true of the higher forms of animal
life and functional activities is equally true of many of the vital
principles that inspired the mature civilization of Greece—they can
not be adequately studied without constant reference to their anterior
stages of evolution. Such knowledge can alone supply the key to the
root significance of many later phenomena, especially in the domain
of art and religion. It alone can indicate the right direction along
many paths of classical research. Amidst the labyrinth of conjecture
we have here an Ariadnê to supply the clue. And who, indeed, was
Ariadnê herself but the great goddess of Minoan Crete in her Greek
adoptive form qualified as the most holy?

" The chasm," remarks Prof. Gardner, " dividing prehistoric from
historic Greece is growing wider and deeper."[2] In some respects
perhaps—but looking at the relations of the two as a whole I venture
to believe that the scientific study of Greek civilization is becoming

[1] From the address of the president delivered to the Hellenic Society, June, 1912.
Reprinted by permission from The Journal of Hellenic Studies, London, vol. 32, pt. 2,
1912. pp. 277–297.
[2] J. H. S., xxxi (1911), p. lix.

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less and less possible without taking into constant account that of the Minoan and Mycenaean world that went before it.

The truth is that the old view of Greek civilization as a kind of "enfant de miracle" can no longer be maintained. Whether they like it or not, classical students must consider origins. One after another the "inventions" attributed by its writers to the later Hellas are seen to have been anticipated on Greek soil at least a thousand years earlier. Take a few almost at random: The Aeginetan claim to have invented sailing vessels, when such already plowed the Aegean and the Libyan seas at the dawn of the Minoan age; the attribution of the great improvement in music, marked by the seven-stringed lyre, to Terpander of Lesbos in the middle of the seventh century B. C.—an instrument played by the long-robed Cretan priests of Hagia Triada some 10 centuries before, and, indeed, of far earlier Minoan use. At least the antecedent stage of coinage was reached long before the time of Pheidôn, and the weight standards of Greece were known ages before they received their later names.

Let us admit that there may have been reinventions of lost arts. Let us not blink the fact that over a large part of Greece darkness for a time prevailed. Let it be assumed that the Greeks themselves were an intrusive people and that they finally imposed their language on an old Mediterranean race. But if, as I believe, that view is to be maintained it must yet be acknowledged that from the ethnic point of view the older elements largely absorbed the later. The people whom we discern in the new dawn are not the pale-skinned northerners—the "yellow-haired Achaeans" and the rest—but essentially the dark-haired, brown-complexioned race, the Φοίνικες or "Red men" of later tradition, of whom we find the earlier portraiture in the Minoan and Mycenaean wall paintings. The high artistic capacities that distinguish this race are in absolute contrast to the pronounced lack of such a quality among the neolithic inhabitants of those more central and northern European regions, whence ex hypothesi the invaders came. But can it be doubted that the artistic genius of the later Hellenes was largely the continuous outcome of that inherent in the earlier race in which they had been merged? Of that earlier "Greece before the Greeks" it may be said, as of the later Greece, capta ferum victorem cepit.

It is true that the problem would be much simplified if we could accept the conclusion that the representatives of the earlier Minoan civilization in Crete and of its Mycenaean outgrowth on the mainland were themselves of Hellenic stock. In face of the now ascertained evidence that representatives of the Aryan-speaking race had already reached the Euphrates by the fourteenth century B. C. there is no a priori objection to the view that other members of the same linguistic group had reached the Aegean coasts and islands at an even

earlier date. If such a primitive occupation is not proved, it certainly will not be owing to want of ingenuity on the part of interpreters of the Minoan or connected scripts. The earliest of the Cretan hieroglyphs were hailed as Greek on the banks of the Mulde. Investigators of the Phaestos disk on both sides of the Atlantic have found an Hellenic key, though the key proves not to be the same, and as regards the linguistic forms unlocked it must be said that many of them represent neither historic Greek, nor any antecedent stage of it reconcilable with existing views as to the comparative grammar of the Indo-European languages.[1]

The Phaestos disk, indeed, if my own conclusions be correct, belongs rather to the eastern Aegean coast lands than to prehistoric Crete. As to the Minoan script proper in its most advanced types— the successive linear types A and B—my own chief endeavor at the present moment is to set out the whole of the really vast material in a clear and collective form. Even then it may well seem presumptuous to expect that anything more than the threshold of systematic investigation will have been reached. Yet, if rumor speaks truly, the stray specimens of the script that have as yet seen the light have been amply sufficient to provide ingenious minds with a Greek—it is even whispered, an Attic—interpretation. For that it is not even necessary to wait for a complete signary of either of the scripts!

For myself I can not say that I am confident of any such solution. To me at least the view that the Eteocretan population, who preserved their own language down to the third century before our era, spoke Greek in a remote prehistoric age is repugnant to the plainest dictates of common sense. What certain traces we have of the early race and language lead us in a quite different direction. It is not easy to recognize in this dark Mediterranean people, whose physical characteristics can be now carried back at least to the beginning of the second millennium before our era, a youthful member of the Aryan-speaking family. It is impossible to ignore the evidence supplied by a long series of local names which link on the original speech of Crete and of a large part of mainland Greece to that of the primitive Anatolian stock, of whom the Carians stand forth as, perhaps, the purest representatives. The name of Knossos itself, for instance, is distinctively Anatolian; the earlier name of Lyttos—Karnessopolis— contains the same element as Halikarnassos. But it is useless to multiply examples, since the comparison has been well worked out by Fick and Kretschmer and other comparative philologists.

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[1] I especially refer to some of the strange linguistic freaks of Dr. Hempl. Prof. A. Cuny has faithfully dealt with some of these in the Revue des Études Anciennes, T. XIV (1912), pp 95, 96. The more plausible attempt of Miss Stawell leaves me entirely unconvinced.

When we come to the religious elements the same Asianic relationship is equally well marked. The great goddess of Minoan Crete had sisters east of the Aegean even more long-lived than herself. The Korybantes and their divine child range in the same direction, and the fetish cult of the double axe is inseparable from that of the Carian labrys which survived in the worship of the Zeus of Labraunda.

Some of the most characteristic religious scenes on Minoan signets are most intelligible in the light supplied by cults that survived to historic times in the lands east of the Aegean. Throughout those regions we are confronted by a perpetually recurrent figure of a goddess and her youthful satellite—son or paramour, martial or effeminate by turns, but always mortal, and mourned in various forms. Attis, Adonis, or Thammuz, we may add the Ilian Anchises,[1] all had tombs within her temple walls. Not least, the Cretan Zeus himself knew death, and the fabled site of his monument on Mount Juktas proves to coincide with a votive shrine over which the goddess rather than the god originally presided. So too, on the Minoan and Mycenaean signets we see the warrior youth before the seated goddess, and in one case actually seem to have a glimpse of the " tomb " within its temenos. Beside it is hung up the little body shield, a mourning votary is bowed toward it, the sacred tree and pillar shrine of the goddess are hard by.[2] In another parallel scene the female mourner lies prone above the shield itself, the divine connection of which is shown by the sacred emblems seen above, which combine the double axe and life symbol.[3]

Doubtless some of these elements, notably in Crete, were absorbed by later Greek cult, but their characteristic form has nothing to do with the traditions of primitive Aryan religion. They are essentially non-Hellenic.

An endeavor has been made, and has been recently repeated, to get over the difficulty thus presented by supposing that the culture exemplified by the Minoan palaces of Crete belongs to two stages, to which the names of " Carian " and "Achaean " have been given. Rough and ready lines of division between " older " and " later " palaces have been laid down to suit this ethnographic system. It may be confidently stated that a fuller acquaintance with the archeological evidence is absolutely fatal to theories such as these.

The more the stratigraphical materials are studied, and it is these that form our main scientific basis, the more manifest it appears that

[1] " Tombs " of Anchises—the baetylic pillar may also be regarded as sepulchral—were erected in many places, from the Phrygian Ida to the sanctuary of Aphrodite at Eryx.
[2] See my " Mycenaean Tree and Pillar-Cult " (J. H. S., 1901), pp. 81, 83, and p. 79, fig. 53
[3] Op. cit., p 78, fig. 52.

while on the one hand the history of the great Minoan structures is more complicated than was at first realized, on the other hand the unity of that history, from their first foundation to their final over-throw, asserts itself with ever-increasing emphasis. The periods of destruction and renovation in the different palaces do not wholly correspond. Both at Knossos and at Phaestos, where the original buildings go back well nigh to the beginning of the middle Minoan age, there was a considerable overthrow at the close of the second middle Minoan period. Another catastrophe followed at Knossos at the end of the third middle Minoan period. At Phaestos, on the other hand, the second, and in that case the final, destruction took place in the first late Minoan period. The little palace of Hagia Triada, the beginnings of which perhaps synchronize with those of the second palace of Phaestos, was overthrown at the same time, but the Minoan sovereigns who dwelt in the later palace of Knossos seem to have thriven at the expense of their neighbors. Early in the second late Minoan period, when the rival seats were in ruins, the Knossian Palace was embellished by the addition of a new façade, on the central court of which the room of the throne is a marvelous sur-viving record. At the close of this second late Minoan age the palace of Knossos was finally destroyed. But the tombs of Zafer Papoura show that even this blow did not seriously break the continuity of local culture, and the evidence of a purely Minoan revival in the third late Minoan age is still stronger in the new settlement of Hagia Triada, which may claim the famous sarcophagus as its chief glory. There is no room for foreign settlement as yet in Crete,[1] though the reaction of mainland Mycenæan influences made itself perceptible in the island [2] toward the close of the third late Minoan period.

Here then we have a story of ups and downs of insular life and of internecine struggles like those that ruined the later cities of Crete, but with no general line of cleavage such as might have resulted from a foreign invasion. The epochs of destruction and renovation by no

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[1] There is no foundation for the view that the later oblong structure at Hagia Triada is a megaron of mainland type. The mistake, as was pointed out by Noack (Ovalhaus und Palast in Kreta, p. 27, n. 24) and, as I had independently ascertained, was due to the omission of one of the three cross walls on the Italian plan. By the close of the Minoan age in Crete (L. M. III, *b*) the mainland type of house seems to have been making its way in Crete. An example has been pointed out by Dr. Oelmann (Ein Achäisches Herrenhaus auf Kreta, Jahrb. d. Arch. Inst. xxvii (1912), p. 38, seqq.) in a house of the reoccupation period at Gournià, though there is no sufficient warrant for calling it "Achaean." It is also worth observing that one of the small rooms into which the large " megaron " of the " Little Palace " at Knossos was broken up in the reoccupation period has a stone-built oven or fireplace set up in one corner. This seems to represent a mainland innovation.

[2] This concluding and very distinctive phase may be described as late Minoan III, *b* (see preceding note) and answers at Knossos to the period of reoccupation, L. M. III, *a*, being represented there by the cemetery of Zafer Papoura, which fills a hiatus on the palace site. Judging from figures on very late lentoid bead seals in soft material (steatite), the long tunic of mainland fashions was coming in at the very close of the Minoan age in Crete.

means synchronize in different Minoan centers, but when we come to regard the remains themselves as stratified by the various catastrophes it becomes evident that they are the results of a gradual evolution. There is no break. Alike in the architectural remains and in the internal decorations, in every branch of art the development is continuous; and though the division into distinct periods stratigraphically delimited is useful for purposes of classification, the style of one phase of Minoan culture shades off into that of another by imperceptible gradations. The same is true of the remains of the early Minoan periods that lie behind the age of palaces, and the unity of the whole civilization is such as almost to impose the conclusion that there was a continuity of race. If the inhabitants of the latest palace structures are to be regarded as "Achaeans," the Greek occupation of Crete must, on this showing, be carried back to Neolithic times. A consequence of this conclusion—improbable in itself—would be that these hypothetical Greeks approached their mainland seats from the south instead of the north.

Who would defend such a view? Much new light has recently been thrown on the history of the mainland branch of the Minoan culture at Mycenae by the supplementary researches made under the auspices of the German Institute at Athens, at Tiryns, and Mycenae. It is now clear that the beginnings of this mainland plantation hardly go back beyond the beginning of the first late Minoan period—in other words, long ages of civilized life in Minoan Crete had preceded the first appearances of this high early culture on the northern shores of the Aegean. From the first there seems to have been a tendency among the newcomers to adapt themselves to the somewhat rougher climatic conditions, and, no doubt in this connection, to adopt to a certain extent customs already prevalent among the indigenous population. Thus we see the halls erected with a narrower front and a fixed hearth, and there is a tendency to wear long-sleeved tunics reaching almost to the knees. An invaluable record of the characteristic fashions of this Mycenaean branch has been supplied by the fresco fragments discovered at Tiryns from which, after long and patient study, Dr. Rodenwaldt has succeeded in reconstructing a series of designs.[1]

These frescoes are not only valuable as illustrations of Mycenaean dress but they exhibit certain forms of sport of which as yet we have no record in Minoan Crete, but which seem to have had a vogue on the mainland side. The remains of an elaborate composition representing a boar hunt is the most remarkable of these, and though belonging to the later palace and to a date parallel with the third late Minoan period shows extraordinary vigor and variety. Cer-

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[1] In course of publication.

tainly one of the most interesting features in this composition—thoroughly Minoan in spirit—is the fact that ladies take part in the hunt. They are seen driving to the meet in their chariots, and following the quarry with their dogs. Atalanta has her Mycenaean predecessors, and the Kalydonian boar hunt itself may well represent the same tradition as these Tirynthian wall paintings.

But the point to which I desire to call your special attention is this: In spite of slight local divergences in the domestic arrangements or costume, the "Mycenaean" is only a provincial variant of the same "Minoan" civilization. The house planning may be slightly different, but the architectural elements down to the smallest details are practically the same, though certain motives of decoration may be preferred in one or the other area. The physical types shown in the wall paintings are indistinguishable. The religion is the same. We see the same nature goddess with her doves and pillar shrines; the same baetylic worship of the double axes; the same sacral horns; features which, as we now know, in Crete may be traced to the early Minoan age. The mainland script, of which the painted sherds of Tiryns have now provided a series of new examples, is merely an offshoot of the earlier type of the linear script of Crete and seems to indicate a dialect of the same language.

In the palace history of Tiryns and Mycenae we have evidence of the same kind of destruction and restoration that we see in the case of those of Minoan Crete. But here, too, there is no break whatever in the continuity of tradition, no trace of the intrusion of any alien element. It is a slow, continuous process of decay, and while at Tiryns the frescoes of the original building were replaced in the second palace by others in a slightly inferior style, those of the Palace of Mycenae, to a certain extent at least, as Dr. Rodenwaldt has pointed out, survived its later remodeling, and were preserved on its walls to the moment of its destruction.

The evidence as a whole must be regarded as conclusive for the fact that the original Minoan element, the monuments of which extend from the Argolid to Thebes, Orchomenos, and Volo, held its own in mainland Greece till the close of the period answering to the third late Minoan in Crete. At this period no doubt the center of gravity of the whole civilization had shifted to the mainland side, and was now reacting on Crete and the islands—where, as in Melos, the distinctive "Mycenaean" megaron makes its appearance. But the return wave of influence can not, in the light of our present knowledge, be taken to mark the course of invading hordes of Greeks.

Observe, too, that in the late Minoan expansion which takes place about this time on the coasts of Canaan the dominant element still seems to have belonged to the old Aegean stock. The settlement of Gaza is "Minoan." Its later cult was still that of the indigenous

Cretan god. In Cyprus, again, the first Aegean colonists brought with them a form of the Minoan linear script, and a civilization which sufficiently proclaims their identity with the older stock.

We must clearly recognize that down to at least the twelfth century before our era the dominant factor both in mainland Greece and in the Aegean world was still non-Hellenic, and must still unquestionably be identified with one or other branch of the old Minoan race. But this is far from saying that even at the time of the first appearance of the Minoan conquerors in the Peloponnese, or, approximately speaking, the sixteenth century B. C., they may not have found settlers of Hellenic stock already in the land. That there were hostile elements always at hand is clearly shown by the great pains taken by the newcomers at Tiryns, Mycenae, and elsewhere to fortify their citadels, a precaution which stands out in abrupt contrast to the open cities and palaces of Crete. In the succeeding period, that of the later Palace of Tiryns, we find on the frescoes representing the boar-hunting scene—dating perhaps from the thirteenth century B. C.—the first definite evidence of the existence of men of another and presumably subject race existing side by side with the Mycenaean. An attendant in a menial position, apparently helping to carry a dead boar, is there depicted with a yellow skin in place of the conventional red, which otherwise indicates the male sex. Is it possible that the paler color was here chosen to indicate a man of northern race?

That there was in fact in the Peloponnese a subject race of Hellenic stock during the whole or a large part of the period of Mycenaean domination is made highly probable by certain phenomena connected with the most primitive of the Greek tribes, namely the Arcadians, whose religion and mythology show peculiar affinities with those of Minoan Crete. Shortly after the break up of the Mycenaean society, during the period of invasion and confusion that seems to have set in about the eleventh century B. C., men of Arcadian speech (who must then have been in possession of the Laconian coast lands) appear in Cyprus in the wake of their former masters, and this Cypriote offshoot affords the best evidence of the extent to which this primitive Greek population had been penetrated with Minoan influences. The very remote date of this settlement is established by the important negative fact that the colonists had left their mainland homes before the use of the Phœnician alphabet was known in Greece. Considering the very early forms of that alphabet at the time when it was first taken over by the Greeks, this negative phenomenon may be taken to show that the Arcadian colonization of Cyprus took place before 900 B. C. The positive evidence seems to indicate a still higher date. Thus the fibulae and vases of the early tombs of the Kuklia Cemetery at Paphos show a distinct parallelism

with the sub-Mycenaean types from those of the Greek Salamis, and point to an impact on Cyprus from the mainland side about the eleventh century before our era, which may well have been due to the advent of the Pre-Dorian colonists from the Laconian shores. These, as we know from inscriptions, brought with them local cults, such as that of Amyklae; but what is especially interesting to observe is the whole-hearted way in which they are seen to have taken over the leading features of the Minoan cult. Fanassa, the Queen, the Lady of the Dove, as we see her at Paphos, Idalion or Golgoi, is the great Minoan goddess. The Paphian temple to the end of the chapter is the Minoan pillar shrine. Were all these Minoan features taken over in Cyprus itself? May we not rather infer that, as the colonists arrived, with at least a sub-Mycenaean element in culture, so too they had already taken over many of the religious ideas of the older race in their mainland home? In the epithet "Ariadnê" itself, applied to the goddess both in Crete and Cyprus, we may perhaps see an inheritance from a pre-colonial stage.

In Crete, where Hellenic colonization had also effected itself in pre-Homeric times, the survival of Minoan religion was exceptionally great. The nature goddess there lived on under the indigenous names of Diktynna and Britomartis. A remarkable example of the continuity of cult forms has been brought to light by the Italian excavation of a seventh century temple at Prinià, containing clay images of the goddess with snakes coiled round her arms, showing a direct derivation from similar images in the late Minoan shrine of Gournià and the fine faïence figures of considerably earlier date found in the temple repositories at Knossos. At Hagia Triada the earlier sanctuary was surmounted by one of Hellenic date, in which, however, the male divinity had now attained prominence as the youthful Zeus Velchanos. As Zeus Kretagenes, he was the object of what was regarded in other parts of the Greek world as a heterodox cult. But in spite of the jeers of Kallimachos at the "Cretan liars" who spoke of Zeus as mortal, the worship persisted to late classical times and points of affinity with the Christian point of view were too obvious to be lost. It is at least a highly suggestive fact that on the ridge of Juktas, where the tomb of Zeus was pointed out to Byzantine times and on a height above his birth cave little shrines have been raised in honor of Αὐθεντὴς Χριστὸς—Christ, the Lord.

In view of the legendary connection of Crete and Delphi, illustrated by the myth of the Delphian Apollo, the discovery there by the French excavators of part of a Minoan ritual vessel has a quite special significance. This object, to which M. Perdrizet first called attention, forms part of a marble rhyton in the form of a lioness's head of the same type, fabric, and material as those found with other

sacred vessels in a chamber adjoining the central shrine of Knossos. It clearly proves that at Delphi, too, the religion of the spot goes back to Minoan times and stands in close connection with a Cretan settlement.

How profoundly the traditions of Minoan and Mycenaean religion influenced the early cult of Greece has been nowhere illustrated more clearly than by the excavations of the British school at Sparta. A whole series of the types of ivory figurines there found are simply derivatives of the scheme of the Minoan goddess with her associated birds and animals. It was the same in Ionia. The Ephesian Artemis has the same associations as the lion goddess of Knossos, and among the jewels found by Mr. Hogarth in the Temple Treasure occur miniature representations of her double axe.

I will venture to point out another feature which the advanced religious art of Greece inherited from Minoan prototypes, such as those which influenced the Spartan ivories. The lions' gate scheme, appropriate to its position in a tympanum, is only one of a series of Late Minoan schemes of the same kind in which the central figure—either the divinity itself or (as in the above case) a sacred column, which as the pillar of the house, stands as the epitome of the temple—is set between two heraldically opposed animals.

Seal impressions from the palace shrine of Knossos show the Minoan goddess in this guise standing on her peak between her lion supporters. The same idea is carried out in a variety of ways on Minoan gems and signets.

The Mycenaean element in Doric architecture itself is generally recognized, but I do not think that it has been realized that even the primitive arrangement of the pediment sculptures goes back to a prehistoric model. That the gabled or pedimental front was itself known in Minoan times may be gathered from the designs of buildings on some intaglios of that date acquired by me in Crete (fig. 1 *a*, *b*).[1] When we realize that the pediment is in fact the functional equivalent of the tympanum on a larger scale, it is natural that an arrangement of sculpture appropriate to the one should have been adapted to the other.

In recently examining the remains of the pedimental sculptures from the early temple excavated by Dr. Dörpfeld at Palaeopolis in Corfù, which have now been arranged by him in the local museum (fig. 2),[2] the observation was forced upon me that the essential features of the whole scheme were simply those of the Mycenaean tympanum. The central divinity is here represented by the Gorgon, but on either side are the animal guardians, in this case apparently pards,

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[1] The gem fig. 1*a* is from Central Crete (steatite). 1*b* is from Siteia (cornelian).

[2] Fig. 2 is taken from a diagrammatic sketch kindly supplied me by Mr. J. D. Bourchier, which accompanied his account of these discoveries in the Times

heraldically posed. Everything else is secondary, and the scale of the other figures is so small that at a moderate distance, all including Zeus himself, disappear from view. The essentials of the architectural design were fulfilled by the traditional Minoan group. The rest was a work of supererogation.

The fragment of a sculptured lion found in front of the early sixth century temple at Sparta was clearly part of a pedimental scheme of the same traditional class.

The extent to which the Minoans and Mycenaeans, while still in a dominant position, impressed their ideas and arts on the primitive Greek population itself argues a long juxtaposition of the two elements. The intensive absorption of Minoan religious practices by the proto-Arcadians previous to their colonization of Cyprus, which itself can hardly be later than the eleventh century B. C., is a crucial instance of this, and the contact of the two elements thus involved itself implies a certain linguistic communion. When, reinforced by fresh swarms of immigrants from the northwest, the Greeks began to get the upper hand, the position was reversed, but the long previous interrelation of the two races must have facilitated the work of fusion. In the end, though the language was Greek, the physical characteristics of the later Hellenes prove that the old Mediterranean element showed the greater vitality. But there is one aspect of the fusion which has a special bearing on the present subject—an aspect very familiar to those who, like myself, have had experience of lands where nationalities overlap. A large part of its early population must have passed through a bilingual stage. In the eastern parts of Crete indeed this condition long survived. As late as the fourth century before our era the inhabitants still clung to their Eteocretan language, but we know from Herodotos that already in his day they were able to converse in Greek and to hand on their traditions in a translated form. It can not be doubted that at the dawn of history the same was true of the Peloponnese and other parts of Greece. This consideration does not seem to have been sufficiently realized by classical students, but it may involve results of a most far-reaching kind.

The age when the Homeric poems took their characteristic shape is the transitional epoch when the use of bronze was giving place to that of iron. As Mr. Andrew Lang well pointed out, they belong to a particular phase of this transition when bronze was still in use for weapons and armor, but iron was already employed for tools and implements. In other words the age of Homer is more recent than the latest stage of anything that can be called Minoan or Mycenaean. It is at most " sub-Mycenaean." It lies on the borders of the geometrical period, and though the archeological stratum with which it is associated contains elements that may be called " sub-Myce-

naean," it is, artistically speaking, a period of barbarism and degradation—a period when the great cities of whose rulers the poet sang had for some two centuries been heaps of ruins. The old art had passed away. The new was yet unborn.

"Homer" lies too high up in time for it to be admissible to seek for illustration among the works of renascent art in Greece, or the more or less contemporary importations, such as Cypro-Phœnician bowls of the seventh or sixth centuries B. C., once so largely drawn on for comparison. On the other hand, the masterpieces of Minoan and Mycenaean craftsmen were already things of the past in the days in which the Iliad and Odyssey took their organic form. Even the contents of the latest Mycenaean graves have nothing to do with a culture in which iron was already in use for cutting purposes and cremation practiced.

How is it, then, that Homer, though professedly commemorating the deeds of Achaean heroes, is able to picture them among surroundings which, in view of the absolute continuity of Minoan and Mycenaean history, we may now definitely set down as non-Hellenic? How explain the modes of combat borrowed from an earlier age and associated with huge body shields that had long been obsolete. Whence this familiarity with the court of Mycenae and the domestic arrangements of palaces that were no more?

I venture to believe that there is only one solution of these grave difficulties, and that this is to be found in the bilingual conditions which in the Peloponnese, at least, may have existed for a very considerable period. The Arcadian-speaking Greek population of that area, which apparently, at least as early as the eleventh century, before our era sent forth its colonists to Cyprus, had, as pointed out, been already penetrated with Minoan ideas to an extent which involves a long previous juxtaposition with the element that formerly dominated the country. They had assimilated a form of Minoan worship, and the hymns and invocations to the Lady of the Dove can hardly have been other than adaptations of those in use in the Mycenaean ritual—in the same way as the Greek hymn of the Dictaean Temple must be taken to reflect an original handed down by Eteocretan choirs.

We may well ask whether a far earlier heroic cycle of Minoan origin might not to a certain extent have affected the lays of the primitive Greek population. When, in a bilingual medium, the pressure of Greek conquest turned the scales finally on the Hellenic side, may not something of the epic traditions of the Mycenaean society have been taken over? Englishmen, at least, who realize how largely Celtic and Romance elements bulk in their national poetry should be the last to deny such a possibility. Have we not, indeed, the proof of it in many of the themes of the Homeric lays, as already

pointed out? They largely postulate a state of things which on the mainland of Greece existed only in the great days of Mycenae.

In other words, many of the difficulties with which we have to deal are removed if we accept the view that a considerable element in the Homeric poems represents the materials of an earlier Minoan epic taken over into Greek. The molding of such inherited materials into the new language and the adapting of them to the glories of the new race was no doubt a gradual process, though we may still regard the work in its final form as bearing the stamp of individual genius. To take a comparison from another field, the arch of Constantine is still a fine architectural monument, though its dignity be largely due to the harmonious incorporation of earlier sculptures. Not less does Homer personify for us a great literary achievement, though the materials that have been brought together belong to more than one age. There is nothing profane in the idea that actual translation, perhaps of a very literal kind, from an older Minoan epic to the new Achaean, played a considerable part in this assimilative process. The seven-stringed lyre itself was an heirloom from the older race. Is it, then, unreasonable to believe that the lays by which it was accompanied were inspired from the same quarter?

And here we are brought up before an aspect of Minoan art which may well stand in relation to the contemporary oral or literary compositions covering part of the Homeric ground. The Homeric aspect of some of its masterpieces has indeed been so often observed as to have become a commonplace. In some cases parts of pictorial scenes are preserved, such as primitive bards delight to describe in connection with works of art. The fragment of the silver vase with the siege scene from Mycenae affords a well-known instance of this. A similar topic is discernible in the shield of Achilles, but in this case a still nearer parallel is supplied by the combat on the shield of Heraklês, described by Hesiod. Here the coincidence of subject extends even to particular details, such as the women on the towers shouting with shrill voices and tearing their cheeks and the old men assembled outside the gates,[1] holding out their hands in fear for their children fighting before the walls. The dramatic moment, the fate of battle still hanging in the balance—so alien to oriental art—is equally brought out by the Mycenaean relief and by the epic description of the scene on the shield, and the parallelism is of special value, since it may be said to present itself in pari materia—artistic composition on metal work.

So too at Knossos there came to light parts of a mosaic composition formed of faïence plaques, and belonging to the latter part of the middle Minoan age. Parts of the composition, of which we have a

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[1] Ἀσπίς, vv. 237 *seqq.* Cf. Tsuntas, Ἐφ. Ἀρχ., 1891, pp. 20, 21, and Μυκῆναι, p. 94 (Tsuntas and Manatt, *Myc. Age*, pp. 214, 215).

fragmentary record, represent warriors and a city, like the siege scene on the silver cup. But we also have glimpses of civic life within the walls, of goats and oxen without, of fruit trees and running water suggesting a literal comparison with the Homeric description of the scenes of peace and war as illustrated on the shield of Achilles. These tours de force of Minoan artists were executed some five centuries before the Homeric poems took shape. They may either have inspired or illustrated contemporary epic. But if Greeks existed in the Peloponnese at the relatively early epoch, the close of the middle Minoan age or the very beginning of the late Minoan, to which these masterpieces belong, they must still have been very much in the background. They did not surely come within that inner palace circle of Tiryns and Mycenae, where such works were handled and admired in the spirit (with which we must credit their possessors) of cultivated connoisseurs. Still less is it possible to suppose that any Achaean bard at the time when the Homeric poems crystallized into their permanent shape had such life-like compositions before his eye or could have appreciated them in the spirit of their creation.

Again we have the remarkable series of scenes of heroic combat best exemplified by the gold signets and engraved beads of the shaft graves of Mycenae—themselves no doubt, as in like cases, belonging to an artistic cycle exhibiting similar scenes on a more ample scale, such as may some day be discovered in wall paintings or larger reliefs on metal or other materials. Schliemann,[1] whose views on Homeric subjects were not perturbed by chronological or ethnographic discrepancies, had no difficulty in recognizing among the personages depicted on these intaglios Achilles or " Hector of the dancing helmet crest," and could quote the Homeric passages that they illustrated. " The author of the Iliad and Odyssey " he exclaims, " can not but have been born and educated amidst a civilization which was able to produce such works as these." Destructive criticism has since endeavored to set aside the cogency of these comparisons by pointing out that, whereas the Homeric heroes wore heavy bronze armor, the figures on the signet are almost as bare as were, for instance, the ancient Gaulish warriors. But an essential consideration has been overlooked. The signets and intaglios of the shaft graves of Mycenae belong to the transitional epoch that marks the close of the third middle Minoan period, and the very beginning of the late Minoan age.[2] The fashion in signets seems to have subsequently undergone

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[1] In the same way epitomized versions of the scenes on the Vapheio cups are found in a series of ancient gems. The taurokathapsia of the Knossos frescoes also reappears in intaglios, and there are many other similar hints of the indebtedness of the minor to the greater art, of which the " Skylla " mentioned below is probably an example.

[2] The curious cuirass, which has almost the appearance of being of basket work, seen on the harvesters' vase and on seal impressions from H. Triada and Zakro has been cited as showing that the corselet was known at a very early period (M. M. III, L. M. I). This particular type, however, has as yet been only found in connection with religious or ceremonial scenes and not in association with arms of offense.

a change, and the later class is occupied with religious subjects. But in the later days of the Palace of Knossos at all events, a series of clay documents attests the fact that a bronze cuirass, with shoulder-pieces and a succession of plates, was a regular part of the equipment of a Minoan knight. Sometimes he received the equivalent in the shape of a bronze ingot or talent—a good suggestion of its weight. On the somewhat later Cypro-Mycenaean ivory relief from Enkomi (where bronze greaves were also found) we see a similar cuirass.[1] This comparison has special pertinence when we remember that in the Iliad the breastplate of Agamemnon was the gift of the Cypriote Kinyras.

A close correspondence can moreover be traced between the Mycenaean and Homeric methods and incidents of combat due to the use of the tall body shield—which itself had long gone out of use at the time when the Iliad was put together. One result of this was the practice of striking at the adversary's throat as Achilles did at Hector's—an action illustrated by the gold intaglio from the third shaft grave. On the other hand the alternative endeavor of Epic heroes to pierce through the " towerlike " shield itself by a mighty spear thrust is graphically represented on the gold bezel of a Mycenaean ring found in Boeotia.[2] The risk of stumbling involved by the use of these huge body shields is exemplified in Homer by the fate of Periphêtês of Mycenae, who tripped against the rim of his shield, " reaching to his feet," and was pierced through the breast by Hector's spear as he fell backward.[3] A remarkable piece of evidence to which I shall presently call attention shows that this particular scene seems to have formed part of the repertory of the engravers of signets for Minoan lords, and that the Homeric episode may have played a part in Chansons de Geste as early as the date of the Akropolis tombs of Mycenae.[4]

Can it indeed be believed that these scenes of knightly prowess on the Mycenaean signets, belonging to the very house of Agamemnon, have no connection with the epic that glorified him in later days? Much may be allowed for variation in the details of individual episodes, but who shall deny that Schliemann's persuasion of their essen-

[1] I may refer to my remarks on this in " Mycenaean Cyprus as illustrated by the British Museum Excavations " (Journ. Anthr. Inst. vol. 30, 1900, pp. 209, seqq., and see especially p. 213). The round targe was now beginning.

[2] In the Ashmolean Museum : as yet unpublished.

[3] Il., XV, 645 seqq.

[4] I note that Prof. Gilbert Murray, who seems to regard the cuirass as a late element, still sums up his views regarding the armor and tactics of the Homeric poems as follows: " The surface speaks of the late Ionian fighting, the heart of the fighting is Mycenaean " (The Rise of the Greek Epic, p. 140). This latter point is the gist of the whole matter. But it is difficult to accept the view that the cultural phase represented by the Homeric poems in their characteristic shape is " late Ionian." The " late Ionians " no longer used bronze for their weapons. Moreover, they were well acquainted with writing and wore signet rings.

tial correspondence was not largely justified? Take the celebrated design on the signet ring from the fourth shaft grave, in which a hero, apparently in defense of a fallen warrior, strikes down his assailant, whose half-retreating comrade, covered behind by a large body shield, aims his spear apparently without effect at the victorious champion. Save that in the case of the protagonist a spear is substituted for a thrusting sword, and that the fallen figure behind the champion is that of a wounded man who still has strength to raise himself on one arm, the scene curiously recalls, even in its details, an episode of the Seventeenth Book of the Iliad. There the Telamonian Ajax, standing before Patroklos's body, strikes down Hippothoos, while Hector behind hurls his spear at Ajax, but just misses his aim.

Much might be added about these pre-Homeric illustrations of Homer, but I will confine myself here to one more example. In the temple repositories of the Palace of Knossos, dating from about 1600 B. C., was found a clay seal impression exhibiting a sea monster with a doglike head rising amidst the waves attacking a boat on which is seen a man beating it off with an oar (fig. 3).[1] But this sea monster is a prototype of Skylla, and though her dogs' heads were multiplied by Homer's time. we have here, in the epitomized manner of gem engraving, the essentials of Ulysses's adventure depicted half a millenium, at least, before the age of the Greek epic. It would appear, moreover, that the same episode was made the subject of illustration in larger works of Minoan art, accompanied, we may suppose, with further details. A fragment of a wall painting found at Mycenae shows part of a monster's head in front of a curving object, recalling the stern of the vessel on the seal impression; and Dr. Studniczka has with great probability recognized in this a pictorial version of the same design.

But, over and above such correspondence in the individual episodes and the detailed acquaintance with the material equipment of Minoan civilization, the Homeric poems themselves show a deep community with the naturalistic spirit that pervades the whole of the best Minoan art. It is a commonplace observation that the Homeric similes relating to animals recall the representations on the masterpieces of Minoan art. In both cases we have the faithful record of eyewitnesses, and when in the Iliad we are presented with a lifelike picture of a lion fastening on to the neck of a steer or roused to fury by a hunter's spear we turn for its most vivid illustration to Minoan gems.

In the transitional epoch that marks the close of the age of bronze in Greece and the Aegean lands the true art of gem engraving was nonexistent.[2] and so, too, in the Homeric poems there is no mention

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[1] See my Report, B. S. A., No. IX, p. 58.
[2] Rudely scratched seal stones of early Geometric date exist, but they are of soft materials.

either of intaglios and signet rings. Yet in the Odyssey just such a scene of animal prowess as formed the theme of so many Minoan gems, a hound holding with teeth and forepaws a struggling fawn, is described as the ornament of Ulysses's golden brooch. The anachronism here involved has been met by no Homeric commentator, for we now know the fibula types of the Aegean "Chalco-sideric age" if I may coin such a word—to which the poems belong, with their inartistic bows and stilts and knobs. It is inconceivable, even did their typical forms admit of it, that any one of these could have been equipped with a naturalistic adjunct of such a kind. The suggested parallels have, in fact, been painfully sought out amongst the fashions in vogue three or four centuries later than the archeological epoch marked by the Homeric poems.[1] As if such naturalistic compositions had anything in common with the stylized mannerisms of the later Ionian art, with its sphinxes and winged monsters and mechanically balanced schemes.

Must we not rather suppose that the decorative motive here applied to Ulysses's brooch was taken over from what had been the principal personal ornaments of an earlier age, when in Greece at least fibulæ were practically unknown,[2] namely, the perforated intaglios, worn generally as periapts about the wrist. An example of one such from eastern Crete with a scene singularly recalling the motive of the brooch is seen in figure 4. It would not have required much license on the poet's part to transfer the description of such a design to a personal ornament of later usage with which he was acquainted. But the far earlier associations of the design are as patent to the eye of the archeologist as are those of a classical gem set in a medieval reliquary.

When in the days of the later epos we recognize heroic scenes already depicted by the Minoan artists and episodes instinct with the

[1] Helbig, for instance (Hom. Epos, p. 277), finds a comparison in a type of gold fibulæ, with double pins and surmounted by rows of gold sphinxes from seventh or sixth century graves of Caere and Praeneste. Ridgeway (The Early Age of Greece, I, 446) cites in the same connection "brooches in the form of dogs and horses found at Hallstatt." The best representative of the "dog" brooches of this class seem to be those from the cemetery of S. Lucia in Carniola (Marchisetti, Necropoli di S. Lucia, presso Tolmino, Tav. XV, figs. 9, 10), where in each case a small bird is seen in front of the hound. A somewhat more naturalistic example gives the key to this; the original of the dog is a catlike animal (op. cit., Tav. XX, fig. 12). We have here, in fact, a subject ultimately derived from the Nilotic scenes, in which ichneumons are seen hunting ducks. The same motive is very literally reproduced on the inlaid dagger blade from Mycenae and recurs in variant forms in Minoan art. The late Hallstatt fibulæ of this class are obviously the derivatives of classical prototypes belonging to the seventh century B. C. (In one case a winged sphinx takes the place of the cat, or pard, before the bird.) These derivatives date themselves from the sixth and even the fifth century B. C., since the last-named example was found together with a fibula of the "Certosa" class. The S. Lucia cemetery itself, according to its explorer (op. cit., p. 313), dates only from about 600 B. C. It will be seen from this how little these late Hallstatt "dog" fibulæ have to do with the design of Ulysses's brooch.

[2] The early "fiddle-bow" type is hardly found before the L. M. III period, when the art of gem engraving was already in its decline.

naturalistic spirit of that brilliant dawn of art, we may well ask how, according to any received theory, such perfect glimpses into the life of that long-past age could have been preserved. The detailed nature of many of the parallels excludes the idea that we have here to do with the fortuitous working of poets' imagination. We are continually tempted to ask, could such descriptive power in poetry go side by side with its antithesis in art, the degraded, conventional art of the period in which the Homeric epos took its final form?

But if a combination of such contradictory. qualities seems in the highest degree improbable, how are we to explain this phenomenon? By what means could this undimmed reflection of a pure, great age have been perpetuated and preserved?

Only in one way, I again repeat, could such passages, presenting the incidents and life of the great days of Mycenae and instinct with the peculiar genius of its art, have been handed down intact. They were handed down intact because they were preserved in the embalming medium of an earlier epos—the product of that older non-Hellenic race to whom alike belong the glories of Mycenae and of Minoan Crete. Thus only could the iridescent wings of that earlier phantasy have maintained their pristine form and hues through days of darkness and decline to grace the later, Achaean world.

Where, indeed, would be the fly without the amber? How could the gestes and episodes of the Minoan age have survived for incorporation in later epic lays without the embalming element supplied by a more ancient poetic cycle? But the taking over and absorption of these earlier materials would be greatly simplified by the existence of such bilingual conditions as have been above postulated. The process itself may have begun very early, and the long contact of the Arcadian branch, whose language most approaches the original speech of Greek epic with the dominant Mycenaeans may have greatly contributed to its elaboration. Even in its original Minoan elements, moreover, we may expect stratification—the period, for instance, of the body shield and the period of the round targe and cuirass may have both left their mark.

The Homeric poems in the form in which they finally took shape are the result of this prolonged effort to harmonize the old and the new elements. In the nature of things this result was often incompletely attained. The evidence of patchwork is frequently patent. Contradictory features are found such as could not have coexisted at any one epoch. It has been well remarked by Prof. Gilbert Murray [1] that "even the similes, the very breath of the poetry of Homer, are in many cases—indeed, usually—adopted ready-made. Their vivid-

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[1] The Rise of the Greek Epic, p. 219. Prof. Murray remarks (op. cit., p. 215) : " The poets of our ' Iliad ' scarcely need to have seen a lion. They have their stores of traditional similes taken from almost every moment of a lion's life."
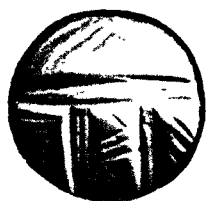
(a)
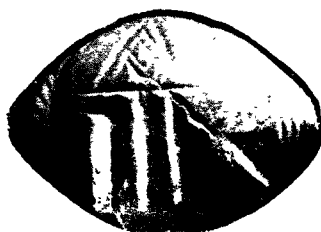
(b)

FIG. 1.—GABLED BUILDINGS ON CRETAN INTAGLIOS (⅓).
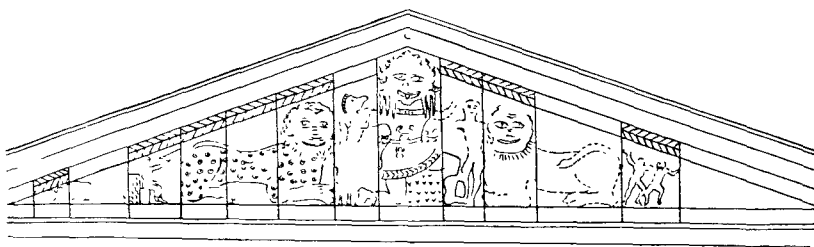
FIG. 2.—PEDIMENT OF TEMPLE AT PALAEOPOLIS, CORFÙ.
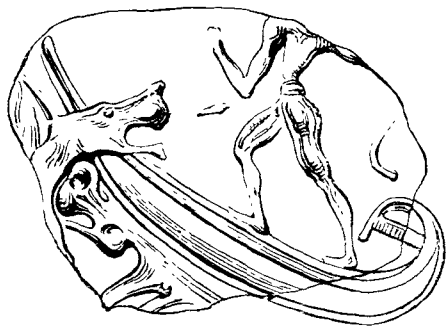
FIG. 3.—CLAY SEALING FROM TEMPLE REPOSITORIES, KNOSSOS ⟨⟩ B.S.A. IX P 50, FIG. 36'.

FIG. 4.—HAEMATITE INTAGLIO FROM E. CRETE WITH DOG SEIZING STAG ⟨⟩

5*a*

5*b*

FIGS. 5*a*-5*b*.—GREEK SIGNET RINGS WITH SILVER
HOOPS AND IVORY BEZELS FOUND IN CRETE (?).

ness, their directness of observation, their air of freshness and spontaneity are all deceptive." Many of them are misplaced and "were originally written to describe some quite different occasion."

Much has still to be written on the survival of Minoan elements in almost every department of the civilized life of later Greece. Apart, moreover, from oral tradition we have always to reckon with the possibility of the persistence of literary records. For we now know that an advanced system of linear script was in vogue not only in Crete but on the mainland side in the latest Mycenaean period.[1]

Besides direct tradition, however, there are traces of a process of another kind for which the early renaissance in Italy affords a striking analogy. In later classical days some of the more enduring examples of Minoan art, such as engraved gems and signets, were actually the subjects of a revival. I venture to think that it can hardly be doubted that a series of early Greek coin types are taken from the designs of Minoan intaglios. Such very naturalistic designs as the cow scratching its head with its hind leg or licking its flank or the calf that it suckles, seen on the coins of Gortyna, Karystos, and Eretria seem to be directly borrowed from Minoan lentoid gems. The two overlapping swans on coins of Eion in Macedonia recall a well-established intaglio design of the same early class. The native goats which act as supporters on either side of a fig tree on some types of the newly discovered archaic coins of Skyros suggest the same comparisons. On the other hand a version of the lions' gate scheme— two lions with their forepaws on the capital of a column, seen on an Ionian stater of about 700 B. C—has some claims, in view of the Phrygian parallels, to be regarded as an instance of direct survival.

A good deal more might be said as to this numismatic indebtedness, nor is it surprising that the civic badge on coins should have been taken at times from those on ancient gems and signets brought to light by the accidental opening of a tomb, together with bronze arms and mortal remains attributed, it may be, to some local hero. Of the almost literal reproduction of the designs on Minoan signet rings by a later Greek engraver I am able to set before you a really astonishing example. Three rings (figs. 5, 6, 7) were recently obtained by me in Athens, consisting of solid silver hoops themselves penannular with rounded terminations in which swivel fashion are set oval ivory bezels, with intaglios on either side, surrounded in each case by a high rim, itself taken over from the prominent gold rim of Egyptian scarab mountings. These bezels are perforated, the silver wire that went through them being wound around the feet of the hoops. From particularities in the technique, the state of the metal and of the ivory, and other points of internal evidence, it is

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[1] Among recent discoveries are a whole series of late Minoan vases from Tiryns with inscriptions representing a mainland type of the developed linear script of Minoan Crete.

impossible to doubt the genuine antiquity of these objects.[1]   They were said to have been found in a tomb in the western part of Crete, reaching Athens by way of Canea, and their owner set no high value on them.[2]   This type of ring with the wire wound around the ends of the hoop is in common use for scarabs, cylinders, and scaraboids in the sixth and fifth centuries B. C., and itself goes back to Minoan or Mycenaean prototypes.[3]   From the style of engraving, however, it seems impossible to date the signet rings in question earlier than about 400 B. C.

The subjects of two of these are a Sphinx with an ibex on the reverse (fig. 5a, b) and another Sphinx coupled in the same way with a Chimaera (fig. 5a, b).   The intaglios are executed in an advanced provincial Greek style, in which, however, certain reminiscences of artistic schemes dating from the first half of the fifth century are still perceptible.[4]

But the designs on the two sides of the third intaglio (fig. 7a and b), though obviously engraved at the same time as the others and by the same hand belong to a very different category.   On one side a man in the Minoan loin clothing with a short thrusting sword in his right hand is struggling with a lion, the head of which is seen as from above.   It will be recognized at once that this scheme corresponds even in details with that of the hero struggling with a lion, engraved on a gold perforated bead or ring bezel found by Schliemann in the third shaft grave at Mycenae.[5]   On the other side of the intaglio, we see a bearded warrior with a girdle and similar

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[1] The exceptional character of these objects and the appearance of Mycenaean motives on one signet side by side with classical subjects on the others made it necessary, in spite of their appearance of undoubted antiquity, to submit them to the severest expertise. I had them examined by a series of the best judges of such objects, but all were unanimous both as to the antiquity of the signets and as to the fact that the ivory had not been recut and reengraved in later times.   Examination of various parts of the surface under a strong microscope confirmed these results.   In order, however, to make assurance doubly sure I decided on a crucial test.   I intrusted to Mr. W. H. Young, the highly experienced formatore and expert in antiquities of the Ashmolean Museum, the delicate task of rebreaking two of the ivory signets along a line of earlier fracture that followed the major axis of each and of removing all extraneous materials due to ᵖᵣᵉvious mendings or restoration.   The results of this internal analysis were altogether conclusive.   The cause of the longitudinal fracture was explained in the case of the signet (fig. 7) by the swelling of the silver pin due to oxidization.   The whole of the metal, transmuted to the purple oxide characteristic of decayed silver, was here within.   In the case of the other signet (fig. 5) this had been replaced by a new pin in recent times, and on removing this the whole of the perforation was visible and proved to be of the ancient character.   The ivory has been attacked on both ends by a tubular drill, the two holes meeting irregularly near the middle.   The modern method of drilling is, of course, quite different.   It is done with a chisel pointed instrument and proceeds continuously from one end.

[2] The correspondence of one of the scenes on the third ring with a type on a gold bead from Mycenae suggests, however, that its prototypes were taken from the mainland side.

[3] An amygdaloid late Minoan or Mycenaean gem representing a ship, set into a silver hoop of this type, found at Eretria, is in my own collection.

[4] As, for instance, in the attitude of the ibex (fig. b) and in the type of the Chimaera. The facing sphinx (fig. a) is carelessly engraved and presents an abnormal aspect.   Of its genuine antiquity, however, there can be no doubt.   (See note 1, p. 634.)

[5] Mycenae, p. 174, fig. 253.

PLATE 3.

6*a*
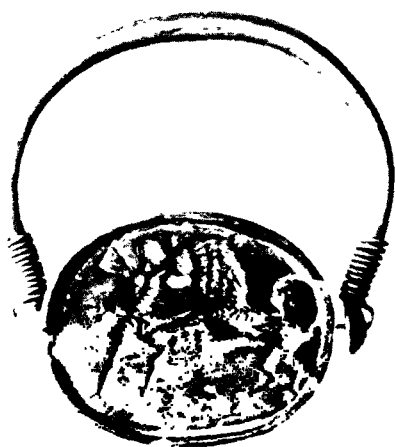
7*a*

6*b*
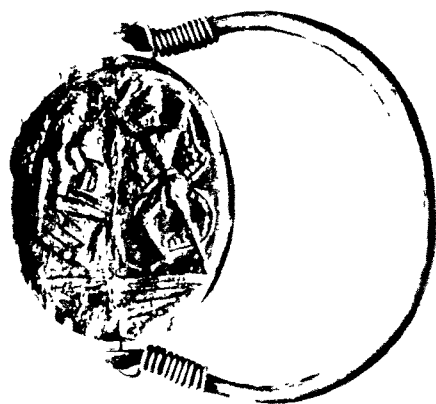
7*b*

FIGS. 6-7.—GREEK SIGNET RINGS WITH SILVER HOOPS AND IVORY BEZELS FOUND IN CRETE. ⅓.

Minoan costume, wearing a helmet with zones of plates and bearing a figure-of-eight shield on his back. Owing to the defective preservation of the surface it is difficult to make out the exact character of the stroke intended or to distinguish the weapon used from the warrior's raised arms. That he is aiming a mortal blow at the figure before him is clear. The latter wears the same narrow Minoan girdle, but his helmet, which is broader, is not so well executed. He is shown in a helpless position, falling backward over the lower margin of a similar shield and holding a sword in his left hand, which, however, is rendered unavailable by his fall.

Here we have a scene closely analogous to that on a sardonyx lentoid from the third shaft grave at Mycenae,[1] except that in the present case the body shield of the falling warrior reaches to his heels. If, as seems probable, this latter detail belongs to the original of the type, and the warrior has tripped backward over the lower rim of his cumbrous body shield, the scene itself would absolutely correspond with the Homeric episode of Periphêtês, to which I have already referred.

> στρεφθεὶς γὰρ μετόπισθεν ἐν ἀσπίδος ἄντυγι πάλτο,
> τὴν αὐτὸς φορέεσκε ποδηνεκέ', ἕρκος ἀκόντων.
> τῇ ὅ γ' ἐνὶ βλαφθεὶς πέσεν ὕπτιος, ἀμφὶ δὲ πήληξ
> σμερδαλέον κονάβησε περὶ κροτάφοισι πεσόντος.[2]

We have here, in fact, the curious phenomenon of a pre-Homeric illustration of Homer revived by a classical engraver.

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[1] Furtwängler, Antike Gemmen, Pl. II, 2, and cf. Reichel, Homerische Waffen, p. 7, fig. 6. A strange and indescribably misleading representation of this gem is given in Schliemann, Mycenae, p. 202, fig. 313.

[2] Il., XV, 645 seqq.

FLAMELESS COMBUSTION.[1]

By CARLETON ELLIS, Montclair, N. J.

[With 1 plate.]

I. INTRODUCTION.

The problem of the influence of hot surfaces upon gaseous combustion is one which, from a purely scientific standpoint, has engaged, for many years past, the attention of Prof. William A. Bone, of Leeds University and the Imperial College, London; and as his recent work has been the direct outcome of earlier scientific investigation, it will be appropriate, by way of introduction, to review briefly the present position of science with respect to this important subject, as stated by Prof. Bone.

One may perhaps best arrive at an understanding of the term "flameless" or "surface" combustion by considering certain facts which differentiate it from the more familiar processes of combustion as they occur in ordinary flames. All hot surfaces have an accelerating influence upon chemical changes in gaseous systems. If, at any temperature, a gaseous system, A, tends to pass over into another system, B, contact with a solid at the same temperature will accelerate the process.

To take a very simple example, if a mixture of hydrogen and oxygen in their combining proportions (electrolytic gas) were maintained in an inclosure with smooth glass walls at a temperature of, say, 450° C., there would certainly be a tendency to form steam, but the rate of change would be negligibly small. If, however, there were brought into the system some porous solid material at the same temperature, so that a large surface was exposed to the gases, the rate of change would at once be rapidly accelerated in the layer of gas immediately in contact with the hot surface. Steam, the product, would diffuse outward from the surface, and the supplies of hydrogen and oxygen at the surface would be renewed by diffusion inward. Thus combustion would proceed heterogeneously at the surface until the transformation of the original electrolytic gas into steam was complete. In the circumstances just cited, the rate of combustion,

although now quite measurable, would probably be insufficient to cause any self-heating of the inclosure. The temperature would remain at 450° C., which is well below the ignition temperature of the combustible mixture, or the point at which a solid would attain even incipient incandescence.

It is therefore necessary to distinguish between two possible conditions under which gaseous combustion may occur, namely: (1) homogeneously, that is to say, equally throughout the system as a whole, at temperatures below the ignition point, slowly and without flame, and at temperatures above the ignition point, rapidly and with flame; and (2) heterogeneously, or only in layers immediately in contact with an incandescent surface (" surface " or " flameless " combustion). Other things being equal, the heterogeneous surface combustion is a faster process than the normal homogeneous combustion of ordinary flames.

The influence of hot surfaces upon combustion at low temperatures seems to have occupied the attention of several chemists (Dulong and Thenard and, independently, Dobereiner, in France, Sir Humphrey Davy, William Henry, Thomas Graham, Faraday, and de la Rive, in England) during the first third of the last century; but no one of these distinguished men succeeded in evolving a satisfactory theory of the phenomenon, nor, with the exception of the famous " Dobereiner lamp," was there any practical outcome of their efforts. In 1836, after a long but abortive controversy between Faraday and de la Rive, interest in the subject was dropped, not to be revived until recent years. Prof. Bone's attention was first drawn to the subject during the course of an investigation on the combustion of hydrocarbons at low temperatures. The subject soon became so absorbingly attractive that he embarked upon what proved to be a long inquiry into the influence of a great variety of hot surfaces upon the combination of hydrogen and oxygen at temperatures below the ignition point. The inquiry has also included other cases of slow combustion; and experiments now in progress in his laboratory will materially advance the science of the subject.

Prof. Bone's experimental results justify the conclusion that the power of accelerating gaseous combustion at temperatures below the ignition point is possessed by all surfaces in varying degrees, dependent upon their chemical characters and physical texture. Moreover, the " activity " of a given surface can be enhanced or diminished at will in a truly marvelous manner by previous special treatment. Thus, for example, in the case of the combination of either hydrogen or carbon monoxide with oxygen, in contact with a nonoxidizable metal or nonreducible oxide, the " activity " of the surface may be greatly stimulated by previous contact with the combustible gas, and,

conversely, may be diminished by previous contact with oxygen. Again, there is abundant evidence that the actual surface combustion is dependent upon a prior " absorption " (or condensation) of the combustible gas, and possibly also of the oxygen, by the surface. To what extent oxygen is involved, is not as yet perfectly clear. The " absorbed " (or condensed) gas becomes " activated " (probably " ionized," as the physicists would call it) by association with the surface. Finally, certain important differences have been established between ordinary homogeneous combustion and heterogeneous surface or flameless combustion. Thus, for example, whereas the presence of water vapor certainly accelerates, if it is not essential to, the homogeneous combustion of carbon monoxide, it greatly retards the heterogeneous combustion of the same gas in contact with a surface such as fire-clay. Again, whereas methane has, in ordinary flames, a much greater affinity for oxygen than either hydrogen or carbon monoxide, a hot surface, by virtue of some " selective " action, will completely reverse this usual order of things—a remarkable circumstance, than which no better proof could be afforded of the reality of surface combustion.

In a discussion before the British Association in 1910, Sir J. J. Thompson insisted that combustion is concerned not only with atoms and molecules, but also with electrons—i. e., bodies of much smaller dimensions and moving with very high velocities—and suggested that " in reference to the influences of hot surfaces in promoting combustion, to which Professor Bone has drawn attention, it was not improbable that the emission of charged particles from the surface was a factor of primary importance." Those who have followed recent developments of the corpuscular theories of electrical action will recall the experimental proof that incandescent surfaces emit enormous streams of electrons, traveling with high velocities; and the action of such surfaces in promoting combustion may ultimately be found to depend on the fact that they bring about the formation of layers of electrified gas, in which chemical changes proceed with extraordinary rapidity.

A distinguishing feature of the new processes employing flameless combustion is, that a homogeneous explosive mixture of gas and air, in the proper proportions for complete combustion (or with air in slight excess), is caused to burn without flame in contact with a granular incandescent solid, whereby a large proportion of the potential energy of the gas is immediately converted into radiant form. The advantages claimed for the new system are: (1) The combustion is greatly accelerated by the incandescent surface, and may be concentrated just where the heat is required: (2) the combustion is perfect with a minimum excess of air; (3) the attainment of very

high temperatures is possible without the aid of elaborate " regenerative " devices; and (4) by reason of the large amount of radiant energy developed, transmission of heat from the seat of combustion to the object to be heated is very rapid.   These advantages are so uniquely combined in the new system that the resultant heating-effect is, for many important purposes, not only preeminently economical, but also easy of control.

II. DIAPHRAGM-HEATING AND ITS APPLICATIONS.

In this process the homogeneous mixture of gas and air is allowed to flow under slight pressure from a suitable feeding chamber, through a porous diaphragm of refractory material, and to burn without flame at the surface of exit, which is thereby maintained in a state of red-hot incandescence.   The diaphragm is composed of granules of fire brick bound together into a coherent block by suitable means.   Its porosity is graded to suit the particular kind of gas for which it is to be used: but for undiluted coal gas, or coal gas containing only a small proportion of water gas, a diaphragm so porous that the gaseous mixture will readily flow through it at a pressure of one-eighth inch water gauge is employed.   It is mounted in a suitable casing; the space inclosed between the back of the casing and the diaphragm constituting a convenient feeding chamber for the gaseous mixture, which is introduced at the back.   Such a mixture may be obtained in either of two ways; namely, (1) by means of suitable connections through a Y-piece with separate supplies of low-pressure gas and air (2 or 3 inches water gauge only is sufficient) ; or (2) by means of an injector arrangement connected with a supply of gas at 2 pounds per square inch pressure.   In this case the gas draws its own air from the atmosphere in sufficient quantity for complete combustion: the proportions of gas and air being easily regulated by a simple device.

To start up a diaphragm, gas is first of all turned on and ignited as it issues at the surface; air is then added gradually until a fairly aërated mixture is obtained.   The flame soon becomes nonluminous and diminishes in size; a moment later, it retreats to the surface of the diaphragm, which at once assumes a bluish appearance; soon, however, the granules at the surface attain an incipient red heat, producing a curious mottled effect; and, finally, the whole of the surface-layer of granules becomes red hot and an accelerated " flameless combustion " comes into play.   All signs of flame disappear, and there remains an intensely glowing surface—a veritable wall of fire but without flame—throwing out a radiant heat which can steadily be maintained as long as required.

The actual combustion in the diaphragm is confined within a very thin layer (one-eighth to one-fourth inch only) immediately below

the surface, and no heat is developed in any other part of the apparatus. While the front of the diaphragm is intensely hot, the back of the apparatus is so cold that one can lay the hand on it. The combustion of the gas, although confined within narrow limits, is perfect; for, when once the relative proportions of gas and air have been properly adjusted, no trace of unburnt gas escapes from the surface. Moreover, the temperature at the surface of the diaphragm can be instantly varied at will by altering the rate of feeding of the gaseous mixture; there is no lag in the temperature response—a circumstance of great importance in operations where a fine regulation of heat is required. The temperature of a diaphragm working on a mixture of coal-gas and air, at a given rate of feeding, depends on whether or not the intense radiation from its surface is impeded; with a freely radiating surface, the temperature of a properly made diaphragm may be maintained at any point up to about 850° C. (say 1,550° F.), according to the rate of supply of combustible mixture. A curious feature of the diaphragm is the freedom from back-firing at this or lower temperature. Even when an explosive gaseous mixture is passed through the porous wall at a velocity very much smaller than the normal speed of back-firing of the mixture, no explosion backward will occur. Such a plain diaphragm may be placed at any desired angle between the horizontal and vertical planes.

The diaphragm method is applicable to a variety of combustible gases. Coal or coke oven gas (either undiluted, or mixed with water gas), natural gas, gasolene-air gas, carburetted water gas, are all well suited in cases where unimpeded radiation is required. I have recently found compressed liquefied gas (Blau gas) to give satisfactory results. Also, Prof. Bone has constructed and successfully operated plane diaphragms of all sizes up to 4 square feet in area, and is able to vouch from experience that their durability and radiant power are unimpaired, even after long-continued use.

INCANDESCENCE NOT DEPENDENT ON EXTERNAL ATMOSPHERE.

A further important point with regard to diaphragm-heating is, that the incandescence of the surface in no way depends upon the external atmosphere. When once the diaphragm has become incandescent, and the proportions of air and gas supplied in the mixing-chamber at the back have been properly adjusted, the surface will maintain its incandescence unimpaired even in an atmosphere of carbon dioxide, nitrogen, or steam.

APPLICATIONS OF DIAPHRAGM-HEATING.

I need hardly point out the many obvious purposes to which " diaphragm-heating " may be applied. Broiling, roasting, toasting, are at once suggested: others will doubtless occur to you—such efficient

means of attaining radiant heat can hardly fail to find new indus-
trial uses. The evaporation and concentration of liquids by means
of radiant energy emitted from a diaphragm fixed in a horizontal
plane above the surface of the liquid is readily carried out.

For example, the evaporation of a solution of sodium silicate
(water-glass) is an operation which could not be satisfactorily per-
formed by the ordinary means of heating the vessel by flame from
below. By the new method, however, only the topmost layers of the
liquid are heated; the radiant energy of the diaphragm is instantly
transmitted to the surface of the liquid, where it is absorbed and
utilized for the evaporation. The sodium silicate separates out as a
skin on the surface of the liquid, it is then dried by the radiant heat,
and at intervals the crust of dry sodium silicate may be skimmed off.
In this way, we are not only able to evaporate the solution with a
great economy of heat, but we are also able to complete the evapora-
tion of highly concentrated solution much more easily than by means
of heat applied from below.

III. INCANDESCENT SURFACE COMBUSTION IN A BED OF REFRACTORY GRANULAR MATERIAL.

This process is applicable to all kinds of gaseous or vaporized
fuels, and to a great variety of both small and large scale industrial
heating purposes. It consists essentially in injecting through a suit-
able orifice, at a speed greater than the velocity of back firing, an
explosive mixture of gas (or vapor) and air, in their combining pro-
portions, into a bed of incandescent granular refractory material,
which is disposed around or in proximity to the body to be heated.

Figure 1 shows the process as applied to the crucible furnace. The
crucible is surrounded by a bed of highly refractory granular ma-
terial. The mixture of gas and air is injected at a high velocity
through a narrow orifice in the base of the furnace, and as it im-
pinges upon the incandescent bed, combustion is instantaneously com-
pleted without flame.

The seat of this flameless combustion is in the lowest part of the
bed; and the burnt gases, rising through the upper layers, rapidly
impart their heat to the bed, maintaining in it a high degree of in-
candescence. Figure 2 shows a similar arrangement for the heating
of a muffle furnace, an arrangement which needs no further expla-
nation.

It is obvious that this process is adaptable to many other furnace
operations, as, for example, the heating of retorts, annealing fur-
naces, and the like. It is not essential that the bed of refractory ma-
terial shall be disposed around the vessel or chamber to be heated; it
may be equally well packed into tubes, or the like, traversing the sub-
stance to be heated. This latter modification is important in relation

to the melting of metals or alloys which are fusible at temperatures below about 600° C., and also in relation to steam raising in multi-tubular boilers. By this process, much higher temperatures are attainable with a given gas than by the ordinary methods of flame combustion without a regenerative system. In fact, we have found that with any gas of high calorific intensity (such as coal gas, water gas, or natural gas), the upper practicable temperature limit is determined by the refractoriness of the material composing the chamber (i. e., the muffle or crucible) to be heated, rather than by the possibilities of the combustion itself. In a crucible fired by coal gas on this system we have readily melted Seger

FIG. 1.—CRUCIBLE FURNACE HEATED BY SURFACE COMBUSTION.

cone No. 39, which, according to the latest determination of the Reichsanstalt in Berlin, melts at 1.880° C. We can also easily melt platinum, showing the possibilities of the method in regard to high temperatures with gas-fired furnaces. Using air preheated to 500° C. with coal gas, a temperature estimated at somewhat over 2,000° C. has been attained. A very resistant chromite, not melting at 1.880° C., was fused in this way. Crucibles of alundum are fused without preheating the air.

For the very high temperatures obtained with coal gas, water gas, or natural gas, Prof. Bone employs a bed composed

FIG. 2.—SURFACE COMBUSTION APPLIED TO A MUFFLE FURNACE.

either of fragments of magnesia, which has been burned at a high temperature, or of a neutral and highly refractory material specially

prepared for this purpose. When the temperature required does not exceed 1,300° C., the bed of refractory material may be composed of a good quality of fire brick, crushed and meshed to a suitable size. As already remarked. the method is applicable to all kinds of gaseous and vaporous fuels, but naturally the maximum temperature obtainable in any given case will depend upon the volume and heat capacity of the products for a given heat development in the bed. Thus, while with actual coal gas, water gas, or natural gas it is possible to attain temperatures up to at least 2,000° C.. about 1,500° C. would probably be the maximum temperature obtainable without regeneration with producer gas of low calorific intensity, such as Mond gas. With some degree of heat recuperation, which in such a case would be quite practicable. this limit could be in all probability considerably exceeded.

The following are the results of a test on a muffle furnace in which the muffle was heated between 815° and 1,425° C., with fully aërated coal gas.

Results of test on a muffle furnace.

[Dimensions of muffle, 9.5 by 5.25 by 3.25 in.]

Temperature in middle of muffle.		Gas consumption to maintain temperature constant. (Cu. ft. per hour, at 15° C.)	Temperature of product.	
° C.	° F.		° C.	° F.
815	1,499	21.0	540	1,004
1,004	1,840	35.3	645	1,195
1,205	2,201	58.0	870	1,598
1,424	2,596	79.0	1,085	1,985

Mean net calorific value of gas = 540 B. t. u. per cu. ft. at 15° C.

The conditions under which the tests were carried out made possible the accurate determination of the rate of gas consumption requisite to maintain the muffle at any constant temperature between 815° and 1,425° C.

The temperatures given in the first two columns are those recorded by a standard thermojunction placed in the middle of the muffle. The temperatures of the escaping products were also ascertained by means of a standard thermojunction. It will be observed that the temperature of the products is in every case some 300° to 400° C. lower than that of the muffle. Even with a muffle temperature of 1,424° C., there was no appearance of flame whatever at the top of the furnace. The gas consumptions recorded in the middle column are extremely economical in comparison with ordinary heating by flame contact. Thus, for example, in a similar test with a muffle

of the same size, heated by flame contact in a furnace of modern design, the gas consumption to maintain the muffle at 1,055° C. (the maximum temperature obtainable) was 105 cubic feet per hour; whereas by interpolation in the above table the consumption in the surface-combustion furnace at the same temperature would have been about 43 cubic feet per hour only.

In a test which I witnessed the consumption of gas by the Bone muffle furnace was just one-half of that of a good type of the ordinary muffle furnace of similar capacity, both being maintained for several hours at 1,500° C.

IV. SURFACE COMBUSTION AS APPLIED TO STEAM RAISING IN MULTITUBULAR BOILERS.

It is well known that hitherto the gas firing of steam boilers has not been very successful, either in thermal efficiency or in the rate of evaporation. All the gases used in this country for raising steam, such as blast-furnace gas, the surplus gas from by-product coke ovens, natural gas, and producer gas of various compositions, have been found amenable to the surface-combustion system. An eminent English blast-furnace engineer estimates that the efficiency of the best type of water-tube boiler fired by blast-furnace gas does not exceed about 55 per cent. Prof. Bone asserts that careful observations, made on a battery of Lancashire boilers fired by blast-furnace gas, evaporating water previously softened to within 4 degrees of hardness with an attachment of the most approved type of economizers (so that the temperature of the burnt gases going to the chimney was reduced to the lowest possible point consistent with good draft), proved that the thermal efficiency did not, under the best of conditions exceed 60 per cent. For boilers fired by coke-oven gas one can safely say that the average thermal efficiency does not exceed 65 per cent, while in exceptional cases it may amount to perhaps 70 per cent.

Figure 3 represents a multitubular boiler of cylindrical section, operated by flameless combustion. It is traversed horizontally by a series of steel tubes, each 3 feet only in length and 3 inches in internal diameter. These tubes are packed throughout with fragments of a suitable refractory material, meshed to the proper size. Into the front end of the tube, where the gaseous mixture is introduced, is fitted a fire-clay plug, through which is bored a circular hole about 0.75 inch in diameter. This plug serves the double purpose of keeping the front end of the boiler cool, and of providing a suitable aperture through which the gaseous mixture may be introduced at a speed much higher than the point of back-firing.

Attached to the front end of the boiler is a mixing-chamber of special design, not shown in detail in the figure. The mixture fed

into the boiler tubes from this chamber consists of the combustible gas, with a proportion of air slightly in excess of that required for complete combustion. The mixture is injected by pressure, or drawn by suction, through the orifice in this fire-clay plug, upon the incandescent material in the tubes. The combustion of the mixture in contact with the incandescent material is complete before it has traversed about 6 inches of the tube from the point of entry. The result is that the core of the material at this part of the tube is maintained at a high temperature, although the areas of actual contact between the hotter material and the walls of the tube are so rapidly cooled by the transmission of heat to the water in the boiler, that they never attain a temperature even approaching red heat.

The combustion having been completed, the remainder of the material acts as a baffle towards the burnt gases as they traverse the tubes at a high velocity, causing them to impinge repeatedly on the walls of the tubes. The usual rate at which the gaseous mixture is fed into the boiler corresponds to the hourly consumption of about 100 cubic feet of coal gas plus six times its volume of air for every tube of the boiler, or an equivalent volume (i. e., equivalent as regards heating capacity) of any other gaseous mixture. Thus, for the ten-tube boiler on which the original experiments were made, the consumption of coal-gas was about 1,000 cubic feet per hour, plus about 5,500 or 6,000 cubic feet of air. These figures indicate the extremely rapid rate at which the mixture is caused to traverse the tubes.
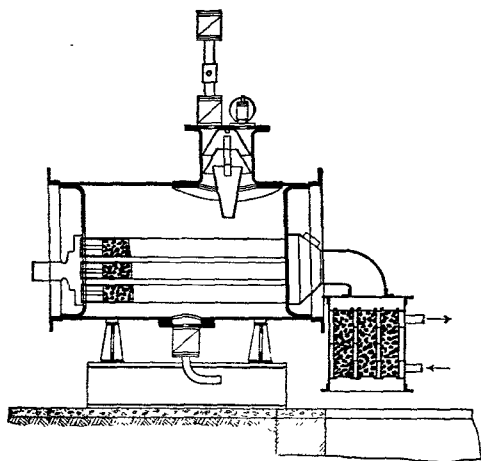
FIG. 3.—EXPERIMENTAL BOILER OPERATED BY FLAMELESS COMBUSTION.

UTILIZATION OF THE HEAT IN THE EXIT GASES.

After the burnt products have traversed the boiler-tubes, their temperature is never more than about 70° C. above that of the water in the boiler (which, of course, depends upon the pressure at which the steam is being generated). This is a much lower temperature than that at which the products of combustion usually pass away from a multitubular boiler. But, in order to increase still further the output of steam, the products are passed through a short tubular feed-

water heater, constructed on the same principle as the boiler. During a test carried out in Leeds, in which steam was generated at 100 pounds above atmospheric pressure, the temperature of the products leaving the boiler-tubes was 230° C.—the actual boiling point of the water being 170° C. These products, still containing a certain amount of valuable heat, were passed through a feed-water heater, only 1 foot long, containing nine tubes, of the same diameter as those in the boiler, packed with granular material. The hot products, continually baffled in their passage through the tubes, readily imparted their heat to the cold feed-water surrounding them; and their temperature was thereby reduced to somewhat less than 100° C.

THE TEN-TUBE EXPERIMENTAL BOILER.

The connections to the front of this boiler consisted essentially of a tube for the supply of gas, and another for the supply of air. The gas and the air were mixed before entering the feeding chamber attached to the front plate of the boiler; the gaseous mixture was burned in the tubes of the boiler; and the products passed outward at the other end into a small chamber, and thence into the feed-water heater.

The mixture of gas and air was passed into the feed chamber of this boiler at a pressure of 17.3 inches water gauge. This pressure was necessary in order to overcome the resistance of the packing of the tubes. The pressure of the products entering the tubes of the feed-water heater was 2 inches water gauge, so that the pressure necessary to force the gas through the zone of combustion, and thereafter through the remainder of the boiler tubes, was about 15 inches. water gauge. In carrying out the test the water was evaporated at 100 pounds above atmospheric pressure; the temperature of the boiling water was therefore 168° C., or 337° F. The temperature of the combustion products leaving the boiler tubes was 230° C. The average temperature of the products leaving the feed-water heater was 95° C., or 203° F. The temperature of the water entering the feed-water heater was 5.5° C., or 42° F., and it was heated to 58° C., or 136.4° F., before entering the boiler, entirely at the expense of the burnt gases.

The ratio between the heat transmitted to the water and the net heat of combustion of the burnt gas in the boiler was 0.94; i. e., over 90 per cent of the heat generated was utilized.

It is one of the prominent merits of the new system that the gas is burned completely with a minimum excess of free oxygen. During the test in question, the average proportion of carbon dioxide in the combustion products was as much as 10.6 per cent, while the oxygen was as low as 1.6 per cent. The most careful examination of the products failed to reveal the presence of the slightest trace of

carbon monoxide, hydrogen, or methane. Therefore, the remainder of the gas was simply nitrogen. Even with as little as 0.5 per cent of oxygen in the products, the combustion of the gas in the tubes is perfect, not a trace of combustible gas escaping.

THE SKININYGROVE 110-TUBE BOILER FOR COKE-OVEN GAS.

That the gas-firing of boilers according to the new system has been advanced beyond the merely experimental stage is proved by the recent erection by the Skininygrove Iron Works Co. (Ltd.), Chuland, Yorkshire, of a 110-tube boiler capable of evaporating not less than 5,500 pounds of water per hour, fired by gas from a new installation of coke ovens adjacent to the blast furnace. As shown in plate 1, figure 1, this boiler is a cylindrical drum 10 feet in diameter, and only 4 feet from front to back; it is traversed by 110 tubes of 3-inch internal diameter, packed with fragments of fire brick. It is worked under the suction of a fan. To the front is attached a device whereby gas at 2 inches water gauge pressure from a suitable feeding chamber, together with a proper proportion of air from the outside atmosphere is drawn (under the suction of the fan) through a short "mixing tube" into each of the 110 tubes of the boiler, where it is burned without flame, in contact with the incandescent granular material. The products of combustion, having traversed the 4 feet of packed tube, pass outward into a semicircular chamber at the back of the boiler, and thence through a duct to the tubular feed-water heater, represented in plate 1, figure 2. A fan attached to the feed-water heater removes the cooled products and discharges them through a short duct into the atmosphere outside the boiler house.

In construction, nothing could be simpler or more compact than a cylindrical shell only 4 feet long by 10 feet in diameter, supported on a casting and requiring neither elaborate brickwork setting nor chimney. The boiler has the further structural advantage over all other multitubular boilers, that the front plate can never be heated beyond the temperature of the water, however much the firing may be forced. This circumstance, coupled with the extremely short length of the tubes, implies an absence of strain and greatly reduces the risk of leaky joints. Another feature of the boiler which makes for efficiency is the steep "evaporation gradient" along the tubes. Under the normal working conditions the "mean evaporation" exceeds 20 pounds per square foot of heating surface, or about twice that of a locomotive boiler. Of the total evaporation no less than 70 per cent occurs over the first third of the tubes, 22 per cent over the next third, and about 8 per cent over the remainder. Such a steep gradient causes a considerable natural circuation of the water in the boiler, a factor of great importance in good working. As to thermal efficiency it seems reasonable to expect that a boiler unit
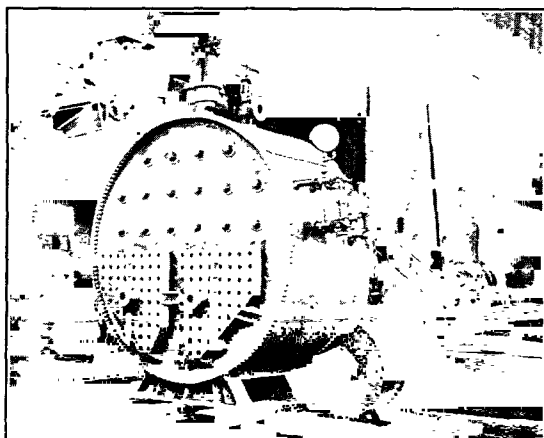
1. SKININYGROVE GAS-FIRED BOILER OPERATED BY FLAMELESS COMBUSTION.
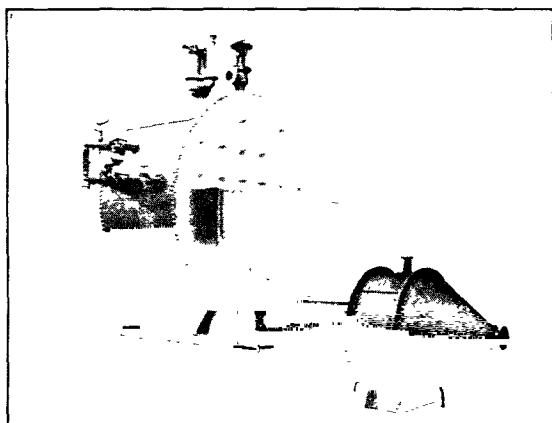
2. FEEDWATER HEATER OF THE SKININYGROVE BOILER.
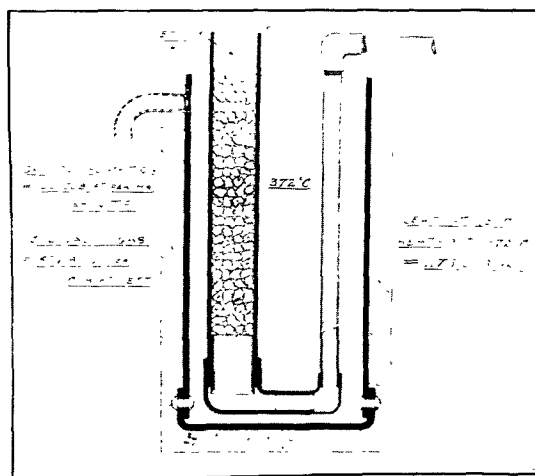
3. TANK FOR MELTING METAL, HEATED BY FLAMELESS COMBUSTION.

which, while evaporating 20 pounds of water per square foot of heating surface, transmits upward of 90 per cent of the net heat of combustion of the gas to the water, and which, if need be, can be forced to a 50 per cent higher "duty" with only a slight drop in efficiency, will stand unrivaled as a steam raiser. Moreover, in the case of a large boiler, of say 100 tubes, "elasticity" may be conferred by arranging the tubes in groups, so that they may be fired up or completely shut off, group by group, successively, in correspondence with variations in the load.

The Skininygrove boiler has proved almost completely automatic in its working, according to the statement of the manager of this plant, who says, also: "The boiler has been off for the inspection of the tubes, which prove to be clean and free from scale, a fact which I attribute to highly rapid ebullition. During the length of time the boiler has been at work we have had no trouble with priming, the steam having been at all times perfectly dry. The average temperature of the waste gases leaving the plant has been from 78 to 80° C., which is ample proof of the boiler's efficiency."

Experiments to determine the value of this type of steam generator as a waste-heat boiler show important economies. Work on oil-fired boilers has also been carried out with satisfactory results.

V. THE MELTING OF EASILY FUSIBLE METALS AND ALLOYS.

It will be readily understood that the principle embodied in the boiler is capable of great extension. Thus, for example, it can be applied to (1) the preliminary concentration of dilute solutions and the heating of liquids generally; (2) the heating of large volumes of air; and (3) the melting of easily fusible metals and alloys.

I will here refer briefly to some experiments on the fusion of metals. Prof. Bone's attention was first drawn to this subject by experts of one of the London gas companies, who represented that there would be a large field of usefulness for the process in melting type metal for large newspapers, which require for their machines a continuous supply of molten type metal. Plate 1, figure 3, represents an iron tank, efficiently lagged and filled to the top with molten lead at a temperature of, say, 50° above its melting point. In the molten bath is fixed an iron tube, 2 or 3 feet long and 3 inches in internal diameter. The tube is packed (like one of the boiler tubes) with a suitable granular refractory material, and there are suitable arrangements for the introduction of the explosive mixture of gas and air which is to be burned in the tube. When once the device is started up, it can be worked continuously for days together. Solid lead is continuously fed into the apparatus, and the molten metal is allowed to run over through the spout indicated in the diagram. Experiments have been carried out with tanks holding up to 8 tons or more of molten metal.

in which a series of combustion tubes are fixed. By means of such an apparatus, lead (or other fusible metals or alloys) may be melted not only very rapidly, but with extraordinary efficiency. The following is the result of a test carried out at the experimental station with a single-tube apparatus:

Lead-melting test.

	Degrees C.	Degrees F.
Temperature of metal charged..	15	60
Temperature of metal tapped...	372	682
Temperature of gases leaving apparatus.....	500	932

Lead melted per hour=1,176 pounds.
Heat required per hour to raise metal from 15° C. to 372° C.=1,176×32.67=38,420 B. t. u.
Gas burnt per hour=100 cu. ft. at N. T. P.
Net calorific value of gas=559 B. t. u. per cu. ft. at normal temperature and pressure.

$$\text{Ratio}=\frac{38.420}{55.900}=0.686.$$

The conditions were so arranged that the mean temperature of the molten metal in the apparatus was 372° C. throughout the test. Lead ingots, each weighing about 30 pounds, were added at intervals of 1.5 minutes, and the molten metal displaced was simultaneously run off into molds. Great care was taken to keep the bath thoroughly molten, and at a temperature within a few degrees of the mean value. Burning gas of net-calorific value of 559 British thermal units per cubic foot, at the rate of 100 cubic feet per hour, it was found possible to raise the temperature of 1,176 pounds of lead per hour from 15° to 372° C.; the temperature of the products of combustion leaving the tube being constant at 500° C., or only 128° above the temperature of the molten metal. Using the latest determination by Spring of the specific heat of lead at temperatures up to and above its melting point, and adopting the usually accepted value for the latent heat of fusion of lead, Prof. Bone estimates that at least 70 per cent of the heat developed was utilized. My observations of this type of heating apparatus, in comparison with externally heated melting pots, show a great difference in fuel consumption in favor of internal heating.

Many other applications of flameless combustion are undergoing exhaustive investigation by Prof. Bone and his able colleague, C. D. McCourt, and in the near future we may look for further interesting developments within the many departments of the field of combustion without flame.

PROBLEMS IN SMOKE, FUME, AND DUST ABATEMENT.

By F. G. COTTRELL.

[With 37 plates.]

The problem of maintaining a clear and unpolluted atmosphere is one which grows with our modern civilization and for the most part as a direct result of it.

There are, to be sure, natural phenomena, such as fog and exhalations from decaying vegetation, with which we have to contend in certain instances, but by far the most serious sources of air pollution are man made.

When coal smoke first came to public notice as the result of the growing use of this fuel, it was looked upon as a distinct and serious menace to the community, and the feeling had grown so strong in England that we find in the time of Queen Elizabeth a law was enacted absolutely prohibiting the burning of coal in London during the sessions of Parliament. Since then the pendulum of public opinion seems, as usual, to have swung to its greatest elongation in the opposite direction, but is now on its return journey, which, let us hope, will be to a position of rational equilibrium where limitation of the smoke evil to the lowest economically practicable point will be rigidly insisted upon without either apathy or hysteria.

SMOKE FROM ORDINARY COMBUSTION.

Although the black smoke resulting from the incomplete combustion of coal or oil fuel is not the only artificial offender, it is undoubtedly the most familiar and perhaps the most important. The rational remedy for the greater part of it is undoubtedly to be found in improved conditions of combustion guaranteeing complete oxidation of these particles of carbon and oily matters within the fire itself, thus eventually discharging them from the chimney as invisible carbon dioxide and water vapor.

This can almost invariably be accomplished if one is willing to make the necessary expenditure for equipment and attention to operation.[1] This means ample and well-constructed combustion cham-

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[1] U. S. Geological Survey Bulletin 334, "The Smoke Problem at Boiler Plants—A Preliminary Report," by D. T. Randall, revised by S. B. Flagg as U. S. Bureau of Mines Bulletin 39. Also U. S. Geological Survey Bulletin 373, "The Smokeless Combustion of Coal in Boiler Furnaces. With a Chapter on Central Heating Plants," by D. T. Randall and H. W. Weeks, revised by Henry Kreisinger as U. S. Bureau of Mines Bulletin 40.

bers, often with the installation of mechanically operated stokers, furnaces and boilers of sufficient capacity to avoid overcrowding even at peak loads, and, above all, a high order of intelligence in supervision of the operations.

In the matter of city ordinances [1] there is often a tendency to lay all the stress on the regulation of existing plants, overlooking or underestimating the fact that much of the trouble comes from inadequate or faulty equipment in the first place. It has been very significant in certain industrial centers to note how some of the older works for a long time opposed municipal regulation as impracticable but later were found to be its staunch advocates. Investigation showed in most cases that their original furnace equipment had in the meantime worn out or become inadequate, and they had thus been forced by business considerations to replace this by new, up-to-date construction in the design of which the smoke problem was given due weight, and under these circumstances they no longer found it impracticable or even difficult to operate in conformity with reasonable smoke ordinances. The lesson that this teaches is the importance of at least some degree of municipal control not only over the operation of existing plants, but also over the construction of new ones. There is the same reason for a city to pass upon the adequacy from a sanitary standpoint of a proposed new power or heating plant within its limits as there is for its similar control of the fire protection and plumbing of a new office building. The regulation of existing sources of smoke always seems, of course, of more immediate importance, but for the future, the control of new construction will undoubtedly prove the determining influence.

Under the conditions of our present-day life and industry, the question arises in each instance. "What will be the cost and is it worth while?" Nor is it meant by this to specially indict the industrial sources of smoke. On the contrary, other things being equal, the individual householder is a far more difficult element to deal with than the large manufacturing plant. Compare, for example, Pittsburgh and Philadelphia. We are wont perhaps to think of Pittsburgh as the typical smoky city and as almost hopeless in this regard, yet to-day to the student of these matters, the cleaning up of smoke in Pittsburgh appears an easier and more practical task than the like service for Philadelphia, for in Pittsburgh the practically universal use of natural gas in the home has left the smoke problem centered simply about the larger industrial uses of fuel. These, from their smaller number and greater individual importance, it is practicable to regulate by trained supervision and control, but

[1] U. S. Bureau of Mines Bulletin No. 49, entitled "City Smoke Ordinances and Smoke Abatement," by Samuel B. Flagg.

in the case of the individual householder, a similar procedure appears well-nigh hopeless.

The most promising solution for the household smoke problem appears to lie in the use (enforced if necessary) of essentially non-smoking fuels. New York City, with its municipal hard-coal regulation, and Pittsburgh, with its natural-gas supply, are good examples of what may be accomplished in this direction. In the case of cities less favorably situated as regards such natural resources we must probably look to the by-products coke oven and other forms of gas producer to separate for us the difficultly manageable soft coals into permanent gaseous and solid products, both of which are essentially fool proof as far as smoke making is concerned, even when placed in the hands of the untrained public. It is interesting here to note that over half a century ago Sir William Siemens predicted from economic considerations that the time would come when all soft coal would first be coked and gasified before use. While this development in our subsequent fuel technique may have been slow and ramified into many forms not at once recognizable, the principles Siemens had before him have certainly underlain a great part of the progress made since his time, and with the widespread interest now being manifested in improved methods of combustion this line of attack bids fair to take a position of ever-increasing prominence.

Another important type of centralized smoke control which has not yet been developed to its full possibilities is that of the central steam-heating plant. A very serious offender as regards smoke in many cities is the moderate-sized steam-heating plant, such as is found in apartment houses and smaller office buildings. The number of these and the amount of smoke which each can produce under careless handling make them a serious item and far more difficult to supervise and control than if consolidated into larger groups with a single furnace plant for each group. Steam distribution with its attendant condensed-water return meets, of course, with sharper limitations than that of either gas or electricity, but even from the economic standpoint, aside from the smoke question, it deserves more serious consideration than it has yet had in municipal engineering.

The ever-widening applications of electricity, especially in power and heating, are also doing much to solve the smoke problem. Even where the electricity has first to be generated from coal, a tremendous advantage is gained by the centralization of furnaces in a few large plants where the highest type of technical skill can be economically devoted to securing perfect combustion.

The small isolated steam-power plant is rapidly disappearing and giving way to the electric motor, primarily for economic reasons,

but incidentally each such substitution helps to solve the smoke problem.

Another important factor is the electrification of railway terminals. In Pittsburgh, for example, it is estimated that about one-third of the total smoke now comes from locomotives. In Chicago the proportion is perhaps even higher, and this element of the problem has been so forcibly realized that the 28 railroads entering that city are now contributing over $150,000 annually toward an investigation conducted by the committee on smoke abatement and electrification of the Chicago Association of Commerce to determine the practicability of general electrification of the lines within the city in order to eliminate this portion of Chicago's smoke nuisance. This probably represents one of the most comprehensive engineering studies ever undertaken along such lines, and is an inspiring illustration of what may be accomplished by intelligently directed public interest. With the growing strength of public opinion on these matters on the one side and the rapid improvement of electric traction technique on the other, it is perhaps not too much to hope that another decade will see locomotive smoke practically eliminated from our larger cities.

To briefly sum it all up, the coal-smoke problem has grown to its most aggravated form from the centralizing tendencies of our civilization, i. e., the concentration of life and industry in large cities, and its solution has already begun and must for the most part be worked out through still further developments of this same centralizing tendency by which the direct use of fuels from which it is easily possible to produce smoke will be entirely taken out of the hands of the individual and small operator and centralized in a relatively few large establishments operating economically under rigid smoke control, which in turn will supply the small consumer with heat and motive power in such forms as gas, coke, steam, and electricity. The key to such a solution is obviously well-directed, intelligent cooperation between municipal authority, private capital, and the individual citizen.

The above covers, of course, only the smoke due to imperfect combustion of fuel, aside from which are many instances of smoke, fumes, and dust arising from various industrial processes which can not be merely "burnt up" into harmless, invisible gases simply by better combustion.

There are, on the one hand, certain true gases, most of them quite invisible but still harmful to animal and plant life and sometimes even to the very buildings of stone and iron; and, on the other hand, such visible clouds of dust or fumes as can be seen arising from chemical and metallurgical works, cement mills, plaster factories, and the like.

THE SULPHUR PROBLEM OF THE SMELTERS.[1]

The treatment and removal of the really gaseous constituents of these trade wastes become such a special problem of chemical engineering in each case that it can hardly be discussed to advantage in the general survey here attempted. There is, however, one case which from its magnitude deserves at least passing comment, viz, the sulphur dioxide gases discharged from smelters operating on the sulphide ores of lead, zinc, and copper, of which the latter, owing to their greater tonnage and higher sulphur content, present the most serious problem. No method has yet been devised which solves this from a practical and economic standpoint for all plants of this character. The most generally applicable method thus far employed has been the manufacture of sulphuric acid. The two chief limits to its commercial applicability in many cases are (1) the lack of a local market for the acid, coupled with the difficulty and expense of its transportation to great distances; (2) the great dilution of the sulphur dioxide with air and other gases in most smelters.

The greatest single use for sulphuric acid to-day is in the manufacture of phosphate fertilizer. The proximity of phosphate rock on the one hand, and of a market for the finished superphosphate fertilizer on the other, are usually determining conditions in this matter. Perhaps the best example of a smelter favorably located in this regard is the Tennessee Copper Co., which has recently installed the largest sulphuric-acid plant in the world. It was driven to this, much against its will, by fume litigation, but is now making more from its acid than from its copper output. As stated, however, its location for such business was ideal, with the phosphate deposits of Tennessee and South Carolina as raw material, and the great southern cotton belt as market for the finished product at its door. It would be difficult to find another plant of this size so favorably located.

When it is considered that there are many smelters in the country, most of them in the West, each of which burns off daily from 250 to 1,000 tons of sulphur from its ores into the atmosphere, and that each ton of sulphur will make three tons of concentrated sulphuric acid and six of superphosphate fertilizer, the industrial problem of its disposition can be better appreciated.

The cost of smelting in most of the large copper plants of to-day ranges from, say, $1.25 to $2 per ton of ore, depending chiefly on cost of labor, fuel, and power, and as a relatively small per cent of this often represents the difference between running at a profit or at a

loss, it will be readily understood that not many cents per ton of ore smelted can be added for special fume treatment unless the product so recovered can be made to pay part of this cost.

Nor, aside from the cost, would it be easy even to throw away such an amount of acid without doing damage to the surrounding country by its getting into the drainage. The total production of sulphuric acid in the United States at present is about 2,500,000 tons per year, of which probably over half goes into fertilizer manufacture, the most important other consumers being the explosive factories, oil refineries, the steel mills, and miscellaneous heavy chemical factories. Over half of the total amount of acid is manufactured from the sulphur of pyrites imported into this country chiefly from Spain. The low water freight from there to our eastern and southern seaboard, where both the raw phosphate and the fertilizer markets already exist, makes this cheaper than to manufacture the acid from waste gases of our western smelters and then pay freight on the finished product.

The discovery in Idaho and Montana, within the last few years, of what are probably the most extensive phosphate-rock beds yet found the world over,[1] is likely to have a very important bearing on the problem in the future; but even so, the freight rates on the finished fertilizer to the southern and eastern markets are still practically prohibitive, and the demand for fertilizer on our virgin soils of the West is developing very slowly. A few days' output of the sulphur from a single one of our large western smelters would supply sufficient acid for the present yearly fertilizer demands of the whole Pacific coast. However, the consumption of fertilizer in the West has more than tripled in the past five years, and eventually this will undoubtedly come to be a factor in the case.

Besides the manufacture of sulphuric acid there are a few uses for sulphur dioxide itself, the largest consumption being in the wood pulp and paper industry, where it is used as a disintegrating and bleaching agent. It is also used as a disinfectant and preservative, and, to a small extent, in refrigerating machinery, but the tonnage represented by the latter application is comparatively small and does not seem to promise great enlargement; still these uses should not be overlooked as possibilities of disposal of part of the material to be handled. In the case of the wood-pulp industry, we are again met by a new complication. The spent liquors from these mills have

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[1] Phosphates: Preliminary report on the Phosphate Deposits in Southeastern Idaho and Adjacent Parts of Wyoming and Utah, by H. S. Gale and R. W. Richards, U. S. Geological Survey Bull. No. 430, 1910, pp. 457–535.

Phosphates in Idaho and Montana, by A. R. Schultz, R. W. Richards, and J. T. Pardee, U. S. Geological Survey Bull. No. 530–H, 1912.

Fertilizer Resources of the United States, by Frank K. Cameron—Message from the President of the United States transmitting a letter from the Secretary of Agriculture, together with a Preliminary Report by the Bureau of Soils on the Fertilizer Resources of the United States—Senate Document No. 190, 2d sess. 62d Cong.

proved nearly, if not quite, as hard to get rid of, and as objectionable to the neighbors, as the smelter fumes themselves; and many suits have been brought against the plants for pollution of streams and other nuisances due to these liquors. So, after all, this would simply mean displacing a nuisance from one industry by extending that from another, although in the end it may prove merely a step in the solving of both problems.

As already stated, many proposals have been made to simply dissolve and wash away the gas in solution, but, while in the pure state it is fairly soluble in cold water, its dilution in average smelter gases and the high temperature of the latter make this mode of collection very difficult on the large scale and even if carried out it would leave a veritable ocean of dilute acid liquors which might easily prove more dangerous to the surrounding country and harder to get rid of than the original gases. The neutralization of this liquor with lime has been suggested and, in fact, this procedure actually obtains at the Ashio smelter in Japan,[1] where specially favorable conditions seem to exist, but, as the weight of lime required in some of our smelters would be over half that of the ore, this, too, is only applicable in very special cases.

Another ingenious suggestion has been to moisten the finely ground slag from the smelter itself, and use the metallic bases therein contained as chemical absorbents for the gas, at the same time unlocking and recovering in solution such of the valuable metals as this slag still contains.[2] Up to the present, however, this method has not proved commercially successful, on account of the slowness of the reaction, but its fundamental idea of combining the two great waste products from the smelter for the purpose of further mutual beneficiation of both is certainly an attractive one. Although it does not appear as necessarily hopeless, the difficulties and uncertainties in the way of its practical application are still certainly very great.

Last but not least is the possible alternative of reducing the sulphur dioxide back to solid sulphur, or, better still, so smelting the ore in the first place that as much of the sulphur as possible is given off and collected as such instead of being burnt to its gaseous oxide as at present. Both of these methods for obtaining the sulphur in the free state are now attracting the serious attention of metallurgists.

The earliest experiment, both in the laboratory and on a practical scale, dates back many years,[3] but recently the subject has again come

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[1] The Japan Excursion of the American Institute of Mining Engineers, Jos. W. Richards, Met. and Chem. Engineering, vol. 10, p. 20–21, Jan., 1912.

[2] The Westby-Sörensen Process, by E. P. Jennings, Eng. and Min. Journ., vol. 86, pp. 418–419, Aug. 29, 1908; also U. S. Pat. 875222, Dec. 31, 1907.

[3] Aeltere und Neuere Verfahren zur Unschädlichmachung des Hüttenrauches durch Abscheidung des Schwefels aus seinen Oxydationsprodukten, by Otto Vogel, Rauch und Staub, 3, 68–71, December, 1912; also Handbook of Metallurgy, by Carl Schnabel, translated by Henry Louis, 2d edition, 1907, vol. 2, pp. 69–76.

prominently to public attention through experiments on a fairly large scale now being conducted in the western smelters, both on the "Thiogen process,"[1] developed by Prof. S. W. Young, of Stanford University, and the "Hall process,"[2] due to W. A. Hall. The outcome of the practical installations and tests under way are being awaited with much interest.

Even if these methods prove successful at some particular plants, we must not jump at the conclusion that the smelter-fume problem in general is forthwith solved, for except where a ready market can be found for the sulphur produced, the extra cost of the oil or other fuel required would be a serious consideration. By far the greater part of the world's production of sulphur goes at present into sulphuric-acid manufacture. so it is evident this brings us back once more to the question of a market for that substance or the discovery of new uses for sulphur itself. Since sulphur, however, weighs only one-third as much as the sulphuric acid which can be made from it and is an inert solid instead of a corrosive liquid, the conversion of the gas to this form at the smelter may aid in the transportation problem even if it is reburned and manufactured into sulphuric acid at its destination.

There is also the chance of so modifying present smelting practice itself that, with the expenditure of little or no extra fuel, part of the sulphur now being burnt up in the furnaces would be distilled off and collected in the unburnt form. Some of the modern developments in smelting practice during the last few years seem to point strongly in this direction. although here again the possible improvements are probably limited to certain branches or departments only of the work, and part of the sulphur would have still to be taken care of by such other methods as already mentioned.

To sum up: The smelter-fume problem as a whole is really made up of so many distinct elements, including character and quantity of ore and fuel supply, processes employed, location of works, transportation facilities, available markets for products, etc., that we can not expect to find any one general solution of the difficulty; but it is encouraging to observe from how many different standpoints the question is being seriously attacked by practical men, and from the sum total of the different improvements applied, and diverse outlets for by-products being found, we may with fair confidence look to steady if not rapid improvement in the general situation.

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[1] The Thiogen Process for Reduction of SO₂ in Smelter Fume, by S. W. Young, Mining and Scientific Press, vol. 103, 386–387, Sept. 23, 1911 ; Thiogen Process Demonstration (illustrated), by L. H. Eddy, Engineering and Mining Journal, vol. 93, 873–874, May 4, 1912. See also Vogel in Rauch and Staub, l. c.

[2] The Hall Ore Desulphurizing Process, by W. A. Hall, Engineering and Mining Journal, vol. 96, 35–36. July 5, 1913. See also Editorial comment and abstracts of patents, The Mining Magazine. vol. 9, pp. 92–93. Aug., 1913. and vol. 10, pp. 141–142. Feb., 1914 ; also 1912 British Patents to W. A. Hall 20757, 20759, 20760, 26595

THE REMOVAL OF INCOMBUSTIBLE SOLIDS AND LIQUIDS.

The removal of the suspended particles of solids or liquids which make up the visible clouds of dust and fume may be considered a purely mechanical problem. no matter how fine these particles are, and as such presents interesting general features easily understood without recourse to highly technical considerations.

The chief methods employed for removing such dust and fume from gases may be classed under the heads of washing. filtering, centrifuging, and electrical precipitation.

WASHING METHODS.

Where washing is employed it is usually accomplished either by a system of fine sprays of water or by bubbling the gases through water or by churning them up with water in various forms of agitators. or by a combination of these. For relatively small volumes of gases having a distinct commercial value—e. g., in the cleaning of fuel gas for domestic use or the scrubbing of iron blast-furnace gas preparatory to use in gas engines—these methods have become well established. but the thoroughness of the scrubbing required with the consequent amount of power consumed, together with the fact that, where the gases contain acid constituents, very corrosive liquors are generated requiring difficult and expensive acid-proof construction of the apparatus. has thus far set rather sharp limitations to the general extension of this method. A vast number of schemes based on these methods have been proposed and many patents have been taken out, but few who have not actually worked with such methods on a really large scale seem to realize the great difficulty they present from the practical and economic point of view when it comes to dealing with very large gas volumes.

FILTRATION METHODS.

The filtration of gases through fabrics, usually in the form of bags, has found a somewhat wider application to large scale work,[1] notably in the zinc and lead industry. The bag house has the advantage over a washing system in that the material is collected in a dry state, and for equal volumes of gas treated the expense of installation and maintenance is generally far less than for water scrubbing. The chief limitations of the bag house have arisen from the impracticability up to the present of securing a suitable fabric which would continuously withstand high temperatures, acids, and other corrosive agents in the gases. Cotton bags are very satisfactory for moderately cool gases free from acids, such as met with in zinc-oxide manufacture. Wool bags, though more expensive, will withstand a somewhat

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[1] See also pp. 671. 674 below and figs. 8 and 19.

higher content of acids and are much used in lead smelting and in some copper smelters, but even their limit is soon reached, and in the majority of copper-smelting plants their use has been considered impractical unless the gases are first neutralized by additions of basic oxides, such as those of calcium or zinc. The resistance to the passage of the gases through the fabric, especially after the solids begin to collect in the pores, is also a serious item in large scale operation, as the fan power required to maintain the draft is often very large.

The use of fine wire screen and of asbestos in place of cotton or woolen fabrics has been repeatedly suggested and extensive experiments have been made with such materials at different plants, but they have not proved generally serviceable, due chiefly to their high cost and the clogging of the pores, rapid corrosion of the wire when fine enough to filter effectively, and the tendency of asbestos to become brittle in highly acid atmospheres.

Besides the bag filters, much less has been made of chambers or towers filled with coke, gravel, sand, sawdust, slag wool, and even asbestos fiber, but for large volumes of gases, especially when they carry a considerable weight of solids, such filter structures if made tight enough to be effective, introduce an enormous resistance and consume a corresponding amount of power, to say nothing of the labor of cleaning, so that their practical use may be considered as confined to rather special cases and relatively small gas volumes.

SETTLING CHAMBERS AND BAFFLES.

Even the interposition of large flues or chambers in the course of the gases on their way to the stack by temporarily decreasing their velocity greatly aids in settling suspended matters and form a part of almost every metallurgical flue system. If baffles in the form of plates or wires are hung in these chambers, their efficiency as dust settlers is greatly increased, but, of course, at the expense of draft, which must usually be compensated for by additional height of stack or fan power. These chambers are, of course, relatively much more effective as settlers for coarse than for fine particles, and it is impractical by their use alone to effectively eliminate real " fume " or smoke. Probably the largest and best illustration of this system is at the Anaconda Copper Mining Co.'s smelter at Great Falls, Mont.[1] A few years ago this plant installed in its flue system a chamber 177 feet wide, 367 feet long, and 21 feet deep, with iron wires hung from top to bottom, spaced about 2 inches apart, each way throughout the chamber, making the aggregate length of wire some 4,000 miles, or about equal to the earth's radius. To overcome the resistance to draft

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[1] " The Great Falls Flue System and Chimney," by C. W. Goodale and J. H. Klepinger, Bulletin American Institute of Mining Engineers. August, 1913. No. 80, pp. 1935–2010.

occasioned, a new stack was also built 50 feet in internal diameter and 506 feet high, the chamber and stack costing over a million dollars, and yet the company considered this a good investment on account of the values recovered from the dust settled by the chamber. Nor is this by any means the largest of the copper-smelting plants in this country. In fact, the same company has another, three times this size, only 175 miles away, at Anaconda. This is mentioned to give some idea of the magnitude of the problems confronting the engineer in smelter-smoke control and the amount of skill and money already expended toward their solution.

APPLICATION OF CENTRIFUGAL FORCE.

Centrifugal force may be applied to remove suspended particles in one of two main ways. In the first of these the gas is brought tangentially into a stationary container of circular horizontal cross section and withdrawn vertically upward through the axis of the container, as in the well-known type of cyclone dust catcher, while the dust particles tend to be thrown out to the periphery and finally drop down into a receptacle provided for them beneath. In the second method the gases are passed axially through a rapidly rotating cylindrical shell, preferably provided with some form of baffles. The dust collects on the shell wall and baffles and may be removed from them in various ways.

The first of these methods is in very general use for gases containing fairly coarse dusts, but its efficiency falls off very rapidly, as might be expected, when we come to deal with smaller particles, and on reaching what we usually understand as fume or smoke the depositing action is practically nil.

The revolving shell type is much more efficient in this regard, but the size and high speed necessary in such machinery for treating the large volumes of gases met with in most instances where it would be of interest have made it rather impractical and it has not come into general use.

ELECTRICAL PRECIPITATION.

The last method of fume and dust collection to which attention will here be drawn depends upon the use of high potential electrical discharges. This has a somewhat special interest for the Smithsonian Institution, not merely on account of the interesting scientific problems which surround it, but also because some three years ago a group of patents pertaining to the subject were offered to the Institution as the basis for a new and unique form of endowment for scientific research. Out of this has grown the Research Corporation, an organization incorporated to administer the technical and business developments of these and other patents and inventions

which may in the future be presented in a similar way to this or other institutions of learning and to return to these institutions for use in scientific research the entire profits arising from such business. As the methods and aims of this new movement have already been elsewhere fully treated,[1] they may here be passed over, but on account of both the intrinsic scientific interest and the Institution's associations with it, the subject of electrical precipitation of suspended particles will be presented in some detail chiefly by compilation from articles which have appeared in various scientific journals[2] amplified somewhat from unpublished notes on the work, furnished for the purpose by members of the technical staffs, at present busied with these developments.

HISTORY OF ELECTRICAL PRECIPITATION.

The removal of suspended particles from gases by the aid of electric discharges is by no means a new idea. As early as 1824 we find it suggested by Hohlfeld[3] as a means of suppressing ordinary smoke, and again a quarter of a century later by Guitard.[4] These suggestions, which do not seem to have stimulated any practical study of the question, were soon entirely forgotten and only brought to light again by Sir Oliver Lodge[5] many years after he himself had independently rediscovered the same phenomena and brought them to public attention in a lecture before the Liverpool section of the Society of Chemical Industry, November 3, 1886.[6] The first recorded attempt to apply these principles commercially appears to have been made at the Dee Bank Lead Works. The general principle of electrical precipitation of suspended matter was at this time patented

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[1] Report of the Secretary of the Smithsonian Institution for the year ending June 30, 1912, pp. 3–5. Also "The Research Corporation, an Experiment in Public Administration of Patent Rights," F. G. Cottrell; Report of the Eighth International Congress of Applied Chemistry, vol. 24, pp. 59–69, September, 1912. Also reprinted Journal of Industrial and Engineering Chemistry, vol. 4, pp. 864–867, December, 1912.

[2] "The Electrical Precipitation of Suspended Particles," by F. G. Cottrell, Journ. Ind. and Eng. Chem., vol. 3, 542–550, August, 1911. "Electrical Fume Precipitation," by F. G. Cottrell, Trans. Amer. Inst. Min. Eng., vol. 43, pp. 512–520, 755–762 (New York meeting, February, 1912). "The Control of Dust in Portland Cement Manufacture by the Cottrell Precipitation Processes," by Walter A. Schmidt; reprint Eighth Inter. Congress Applied Chem., vol. 5, pp. 117–124, 1912; also reprinted from Journal Industrial and Engineering Chemistry, vol. 4, pp. 719–723, October, 1912. "Electrical Precipitation of Suspended Particles," by Linn Bradley, Trans. Amer. Electrochemical Soc., vol. 22, pp. 489–497, 1912. "Electrical Precipitation of Cement Dust," Philip S. Taylor, Journ. Electr. Power and Gas, Mar. 14, 1914.

[3] "Das Niederschlagen des Rauchs durch Electricität Hohlfeld," Kastner Archiv. Naturl., vol. 2, pp. 205–206 (1824).

[4] C. F. Guitard, Mechanics Magazine, Nov., 1850.

[5] Historical Note on "Dust Electrification and Heat," O. J. Lodge, Nature, vol. 71. p. 582 (1905).

[6] "The Electrical Disposition of Dust and Smoke with Special Reference to the Collection of Metallic Fumes and to a Possible Purification of the Atmosphere," Journ. Soc. Chem. Ind., vol. 5, pp. 572–576 (1886), with appended bibliography.

PLATE 1.
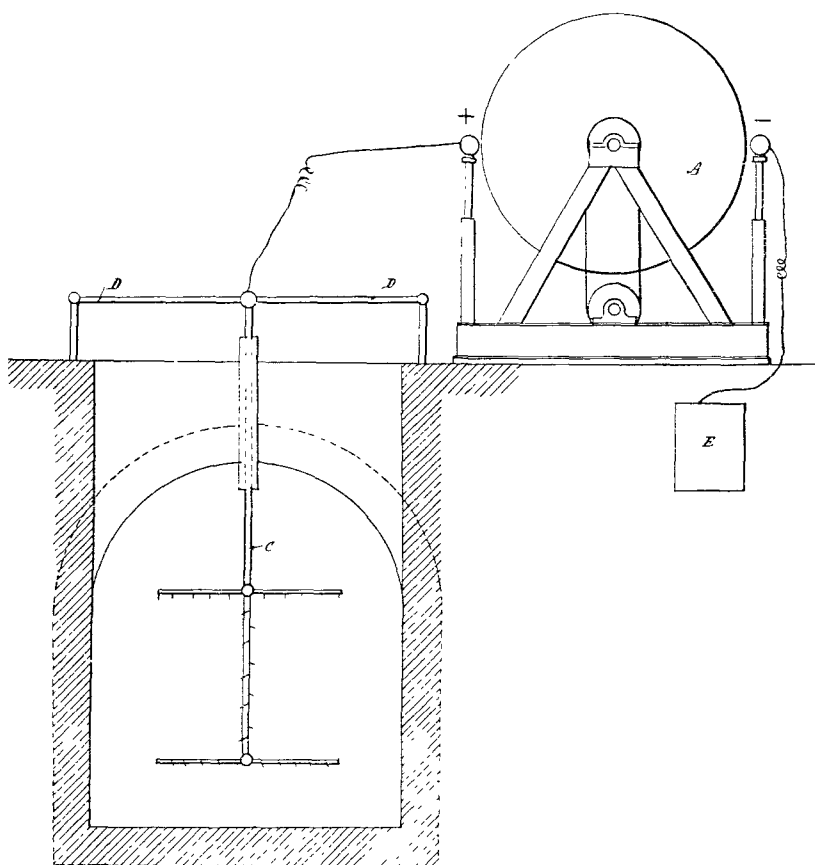
FIG. 1.—DRAWINGS ACCOMPANYING EARLIEST PATENT ON PRECIPITATION (WALKER, 1884).

by Alfred O. Walker of the above firm in several countries,[1] but these patents have long since expired. The apparatus was installed in 1885 by the works manager, W. M. Hutchings, with the cooperation of Prof. Lodge, and was briefly described by the former [2] just before its completion as consisting of a system of metallic points situated in the flue from the lead furnaces, and excited from two Wimshurst influence machines with glass plates 5 feet in diameter, each machine being driven by a 1-horsepower steam engine. Figure [3] 1 reproduces the drawing accompanying Walker's United States patent specification, *A* being the Wimshurst machine and *B* the flue carrying the gases to be treated.

The apparatus undoubtedly did not in practice fulfill expectations, as we find nothing further of it in the literature. The most apparent weakness of the project lay, perhaps, in the reliance on the Wimshurst machine, which had then just been brought out and from which a great deal more was anticipated [4] than has been justified by experience, at least as far as commercial applications are concerned. Almost simultaneously with Walker, and apparently without knowledge of his and Lodge's work, Dr. Karl Moeller, of the firm of K. & Th. Moeller, of Brackwede, Germany, secured a patent [5] on electrical precipitation. The patent specification itself appears, however, to be the only published record of this work. The idea was, it is understood, suggested by an article [6] dealing with the disturbing influence on electrometer measurements due to dust in the air.

After this an occasional patent [7] or article [8] served to keep the subject in the public eye, and in 1903 Lodge took out a patent [9] covering the use of the then new mercury arc for rectifying high potential alternating currents for this purpose, but none of these patents seem to have been carried into successful commercial operation on the large scale in the chemical or metallurgical industries.

Some eight years ago, while studying various methods for the removal of acid mists in the contact sulphuric-acid process at the University of California, the author had occasion to repeat the early experiments of Lodge and became convinced of the possibility of de-

[1] Great Britain, Patent No. 11120, Aug. 9, 1884; Belgium, 68927, May 19, 1885; Spain, 7211, July 10, 1885; Germany, 32861, Feb. 27, 1885; Italy, 18007, Mar. 31, 1885; United States, 342548, May 25, 1886.

[2] Berg.- und Hüttenmännisch Zeitung, vol. 44, pp. 253–254 (1885).

[3] The figures in this paper are numbered consecutively and printed on plates.

[4] A. O. Walker, Engineering (Lond.), vol. 39, pp. 627–628 (1885). G. Tissandier, London Electrician, vol. 17, p. 33 (1886).

[5] Ger. Pat. 31911, Kl. 12, 1884.

[6] By Robt. Narwald, Wied. Ann. vol. 5, pp. 460–499 (1878).

[7] Lorrain, British Pats. 6495 and 6567 (1886); Thwait, U. S. Pat. 617618, Jan. 10, 1899; Hardie, U. S. Pat. 768450, Aug. 23, 1904; Blake, U. S. Pat. 913941, Mar. 2, 1909; Dion, 925626, June 22, 1909.

[8] J. Wright, Elect. Rev. (Lond.), vol. 47, p. 811, Nov. 23, 1900; see also Jour. Roy. Sanitary Institute, vol. 27, p. 42.

[9] Brit. Pat. 24305 (1903); U. S. Pat. 803180, Oct. 31, 1905.

veloping them into commercial realities. The subsequent work may fairly be considered as the reduction to engineering practice as regards equipment and construction of the fundamental processes long since laid open to us by the splendid pioneer work of Lodge, a feat vastly easier to-day than at the time of Lodge and Walker's original attempt.

THEORY OF ELECTRICAL PRECIPITATION.

The precipitation of suspended matter, whether in gases or liquids, may be accelerated by electricity in the form of either direct or alternating current, but the mode of action and the type of problem to which each is best applicable differ in certain important respects.

Where an alternating electromotive force is applied to a suspension the action consists for the most part in an agglomeration of the suspended particles into larger aggregates out in the body of the suspending medium and a consequently more rapid settling of these aggregates under the influence of gravity.

Thus, it has been stated that if powerful Hertzian waves are sent out under proper conditions into foggy air the alternating fields set up in space cause an agglomeration of the particles of liquid into larger drops, which then settle much more rapidly. Considerable work aimed at the application of these phenomena to the dispelling of fog on land and sea was said to have been done some years ago in France and England, but very little as to definite results appears to have been published. Another application of alternating current along these lines is found in a process now in use in the California oil fields for separating emulsified water from crude oil.[1]

Alternating current may thus be used to advantage where the masses of fluid to be treated are fairly quiescent, and a simple agglomeration of the suspended particles into larger aggregates is sufficient to effect separation by gravity or otherwise.

In the case of the large volumes of rapidly moving gases in smelter flues the agglomerating and settling process is, however, too slow even when the flues are expanded into as large dust chambers as are commercially feasible. It is in such cases that unidirectional current methods have been particularly important.

If we bring a needle point connected to one side of a high potential direct-current line opposite to a flat plate connected to the other side of the line we find that the air space between becomes highly charged with electricity of the same sign as the needle point, irrespective of whether this is positive or negative, and any insulated body brought into this space instantly receives a charge of the same sign. If this body is free to move, as in the case of a floating particle,

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[1] See " Dehydration of Crude Petroleum, a New Electrical Process," Arthur T. Beazley, The Oil Age (Los Angeles), vol. 3, pp. 2–4, Apr. 21, 1911.

it will be attracted to the plate of opposite charge and will move the faster the higher its charge and the greater the potential gradient between the point and plate.

Even if there are no visible suspended particles the gas molecules themselves undergo this same process, as is evidenced by a strong wind from the point to the plate, even in perfectly transparent gases. The old familiar experiment of blowing out a candle flame by presenting it to such a charged point is simply another illustration of the same phenomena.

As above indicated, the first step toward practicability was of necessity a commercially feasible source of high-tension direct current. The obstacles to building ordinary direct-current generators for high voltages lie chiefly in difficulties of insulation, and if this is avoided as to individual machines by working a large number in series the multiplication of adjustments and moving parts intrudes itself. On the other hand, high potential alternating current technique has in late years been worked out most thoroughly, and commercial apparatus up to 100.000 volts and over has been available for some years in the market.

The procedure actually used in the installations described below is diagrammatically illustrated in the early Patent Office drawing (fig. 2), and consists in transforming the alternating current from an ordinary lighting or power circuit P up to some 20,000 to 75.000 volts through the transformer O, and then commutating this high potential current into an intermittent-direct current by means of a special rotating contact maker J driven by a synchronous motor L. This unidirectional current is applied to a system of electrodes in the flues carrying the gases to be treated. In the particular form shown in the drawing the wall of the chamber A itself acts as one electrode, the other electrode C being suspended within it. The heating circuit h and inlet for clean gas G are merely for protection of the insulation from condensation of acid and moisture.

The electrodes are of two types corresponding to the plate and point in the experiment above cited. The construction of electrodes corresponding to the plate presents no special problem, as any smooth conducting surface will answer the purpose. With the pointed or discharge electrodes it is quite otherwise, and the working out of practical forms for these proved the key to the first commercially successful installations.

In laboratory experiments when the discharge from a single point or a few such was being studied fine sewing needles or even wire bristles answered very well, but when it was attempted to greatly multiply such discharge points in order to uniformly treat a large mass of rapidly moving gas at moderate temperatures great dif-

ficulty was encountered in obtaining a powerful and, at the same time.
effective distribution of current.

It may be of interest to note that the clue to the solution of this
difficulty came from an almost accidental observation. Working one
evening in the twilight, when the efficiency of the different points
could be roughly judged by the pale luminous discharge from them,
it was noticed that under the particular conditions employed at the
time this glow only became appreciable when the points had ap-
proached the plates almost to within the distance for disruptive
discharge, while at the same time a piece of cotton-covered magnet
wire, which carried the current from the transformer and commutator
to the discharge electrodes, although widely separated from any
conductor of opposite polarity, showed a beautiful uniform purple
glow along its whole length. The explanation lay in the fact that
every loose fiber of the cotton insulation, although a relatively poor
conductor compared to a metallic wire, was still sufficiently con-
ductive from its natural hygroscopic moisture to act as a discharge
point for this high potential current, and its fineness and sharpness.
of course, far exceeded that of the sharpest needle or thinnest metallic
wire. Acting on this suggestion, it was found that a piece of this
cotton-covered wire when used as a discharge electrode at ordinary
temperature proved far more effective in precipitating the sulphuric-
acid mist, which was then the object of study, than any system of
metallic points which it had been possible to construct. Perhaps
the greatest advantage thus gained lay in the less accurate spacing
demanded between the electrodes of opposite polarity in order to
secure a reasonably uniform discharge. Much of the importance of
this discovery at the time lay in the limited potentials of a few
thousand volts then available to the experimenters in their laboratory
work.

In practice, of course, a more durable material than cotton was
demanded for the hot acid gases to be treated, and this was found
in asbestos or mica, the fine filaments of the one and the scales of the
other supplying the discharge points or edges of the excessive fine-
ness required. These materials were twisted up with wires or other-
wise fastened to suitable metallic supports to form the discharge elec-
trodes in such wise that the current had to pass only a short distance
by surface leakage over them, the slight deposit of moisture or acid
fume naturally settling on them serving to effect the conduction.
With the further development of the electrical technique to provide
the far higher voltages now being used in commercial operation, the
choice and design of electrodes has become much more flexible, includ-
ing simple metallic wires, sharp metallic strips, and the like. In
fact, the very phenomena of so-called corona loss or direct leakage
from the wire into the air on high-tension transmission lines, which

PLATE 2
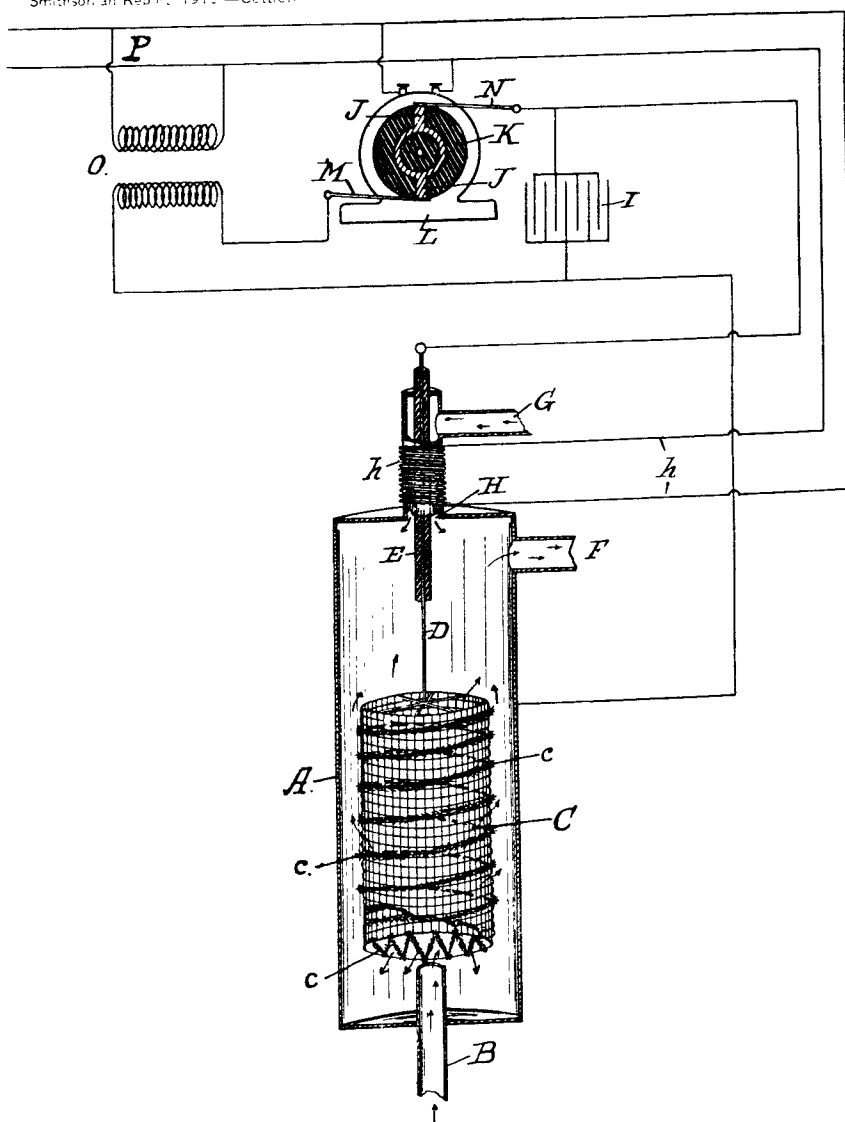
FIG. 2.—PATENT OFFICE DRAWINGS OF FIRST COMMERCIALLY SUCCESSFUL SYSTEM OF ELECTRICAL PRECIPITATION (COTTRELL, 1903).

PLATE 3.
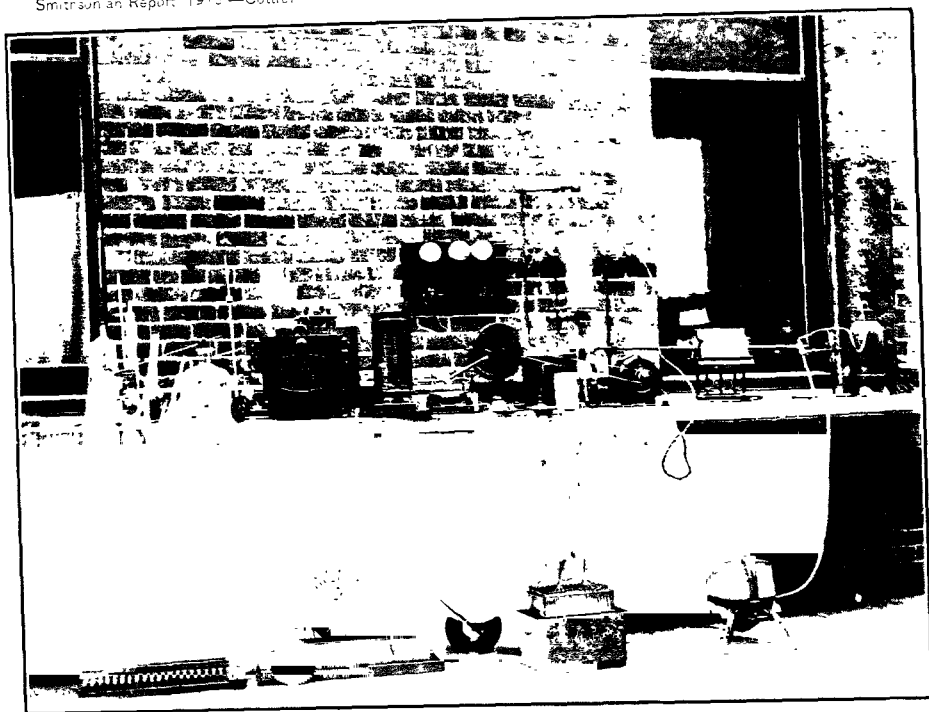
FIG. 3.—GENERAL ARRANGEMENT OF EXPERIMENTS ON SULPHURIC ACID MISTS, UNIVERSITY OF CALIFORNIA, 1906

are to-day the chief stumbling block of the power companies in going very far above 100,000 volts on these lines, become exactly what is desired in the processes of precipitation, and with the voltages now used a bare metal wire of moderate size or the relatively thin edge of a metallic sheet may be made to furnish an excellent discharge.

The construction and arrangement of the electrodes, as also of the chamber containing them, naturally varies very widely with the conditions to be fulfilled under the varied applications to which the process may be put. Some of the more general features of this work are described in patents[1] already issued in this and foreign countries, while further details and modifications are covered in other patents not yet issued from the various patent offices. The accompanying photographs give perhaps a better idea of the gradual development of the work than any detailed description which would be possible in the space here at command.

<div align="center">LABORATORY EXPERIMENTS.</div>

Figure 3 is the apparatus used for the original laboratory experiments in the spring of 1906. Sulphuric-acid mist was generated by bubbling the gas from the little contact sulphuric-acid plant, seen on the table, through water in the U tube beneath the inverted glass bell jar (A),[2] whose inner walls were quickly wetted sufficiently with acid to act as the collecting electrode, a wire being inserted alongside of the stopper through which the U-tube connected with the bell jar and served to connect the jar walls to the induction coil on the left, the latter acting as the step-up transformer (O). This coil received alternating current at 110 volts from the lighting circuit and gave about 3,700 volts at its secondary. The other high potential terminal of the induction coil was connected to the discharge electrode (C) within the bell jar through a make and break (M J N), operated by the synchronous motor (L). This latter was improvised by substituting a plain iron cross for the squirrel-cage armature in an ordinary fan motor operated from the same 110-volt line as the induction coil and brought into step by the induction motor on the right. A momentary contact with the discharge electrode was thus established once each complete cycle at the peak of the voltage wave and served to charge this electrode to the maximum voltage of the line, always with the same polarity. As stated above, electrical precipitation takes place no matter whether the discharge electrode is made the positive or negative, and the direction of the discharge and deposit is independent of the polarity and determined only by the

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[1] U. S. Pats. 866843, 895720, 945917, 1016476, 1035422, and 1067974. The second of these also practically reprinted by Eng. Min. Journ., vol. 86, pp. 375–377 (1908), Germ. Pats. 258435, 265964, and 270757, and corresponding patents in various other countries. See also in this connection German Pats. 208740, 230570, and 238958.

[2] The letters in parentheses refer to corresponding parts in the diagram (fig. 2).

size, shape, and surface of the opposing electrodes; but it is found in practice that the negative discharge is much the more stable and can be run at higher current without danger of disruptive discharge, so that it has now become standard practice to make the discharge electrodes the negative and the grounded collection electrodes the positive.[1]   In order to help maintain the charge on the electrode in the interval between these contacts, the Leyden jar (I) seen in the picture was connected in parallel with the electrodes.   The wire leading to the jar walls or collecting electrode was usually grounded for convenience and safety, as, in fact, has been done throughout all the practical installations.   This leaves but one high-potential conductor to deal with in each precipitation chamber and greatly increases the safety of operation.

Figure 4 is a closer view of the precipitation chamber through which the acid fume is being blown at the rate of about 20 liters per minute, the electric current being shut off of the apparatus.   Figure 5 shows the effect of turning on the electric current with the same gas steam still flowing.

The discharge electrode in this case consisted of a cylinder of wire screen (C), wrapped with a few turns of asbestos sewing twine (c) and suspended by a wire passing through a glass tube as shown.   The suspended particles of acid were driven away from the asbestos filaments and deposited on the walls of the bell jar, finally running down into the U tube below.

The next undertaking was to duplicate these experiments on a scale some two hundred-fold larger.   This was carried out during the same summer at the Hercules works of the E. I. du Pont de Nemours Powder Co. at Pinole, on San Francisco Bay, where the contact gases from one of their Mannheim contact sulphuric acid units were employed.

Figures 6 and 7 are photographs taken about a minute apart with the same current of fume-laden gases passing into the precipitation chamber, but with the electric current respectively off and on.   The apparatus was the same in general principle as the small laboratory unit described above.   The precipitated acid drained off from this precipitation chamber into the carboy on the right.   Current was supplied from three 1-kilowatt 110-volt to 2,200-volt transformers connected in series on their 2,200 volt side to give 6,600 volts.   In this apparatus the power consumption was about one-fifth of a kilowatt, and between 100 and 200 cubic feet of gas per minute could readily be treated.

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[1] The Positive and Negative Corona and Electrical Precipitation, W. W. Strong. Trans. Amer. Inst. Elect. Eng., vol. 32, pp. 1305-1314, Cooperstown meeting, June 27, 1913. Also U. S. Pat. 1067974, Cottrell, July 22, 1913.

PLATE 4.
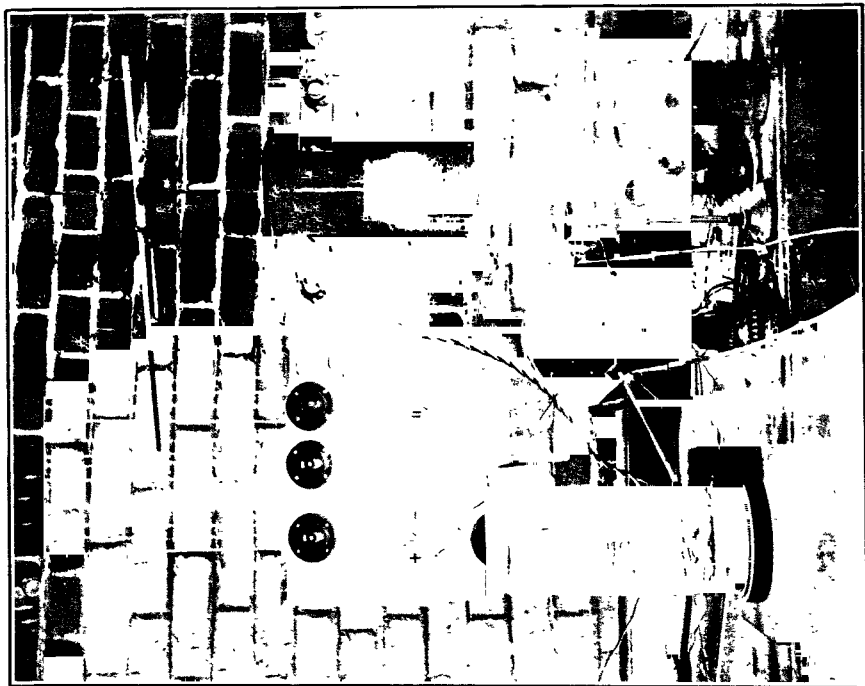
FIG. 5.—ENLARGED DETAIL OF EXPERIMENTAL PRECIPITATOR, ELEC-
TRIC CURRENT ON.

FIG. 4.—ENLARGED DETAIL OF EXPERIMENTAL PRECIPITATOR, ELEC-
TRIC CURRENT OFF.

PLATE 5.

FIG. 7.—PRECIPITATOR AT SULPHURIC-ACID PLANT, ELECTRIC CURRENT ON.

FIG. 6.—PRECIPITATOR AT SULPHURIC-ACID PLANT, ELECTRIC CURRENT OFF.
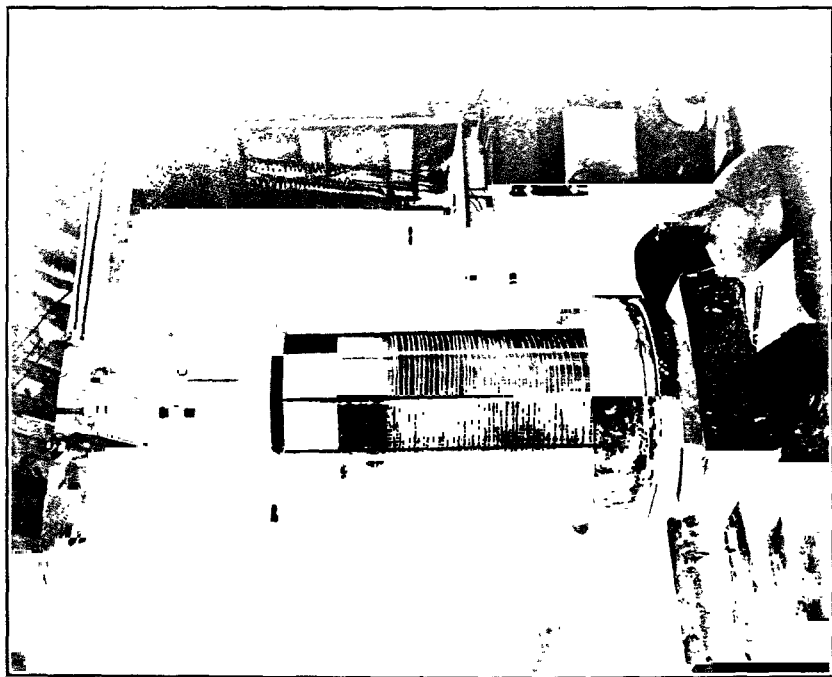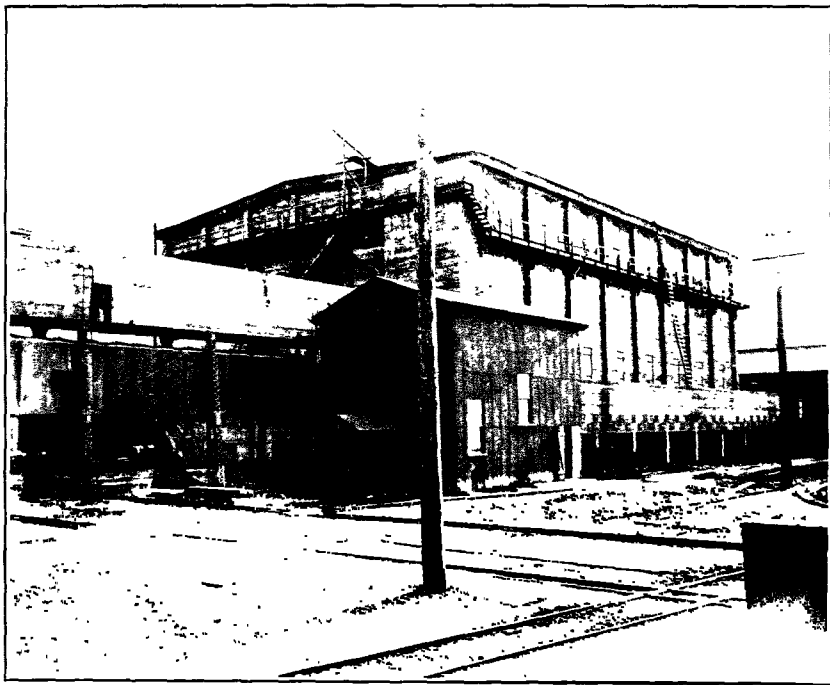
FIG. 8.—BAG HOUSE AT SELBY SMELTER.

PLATE 7.
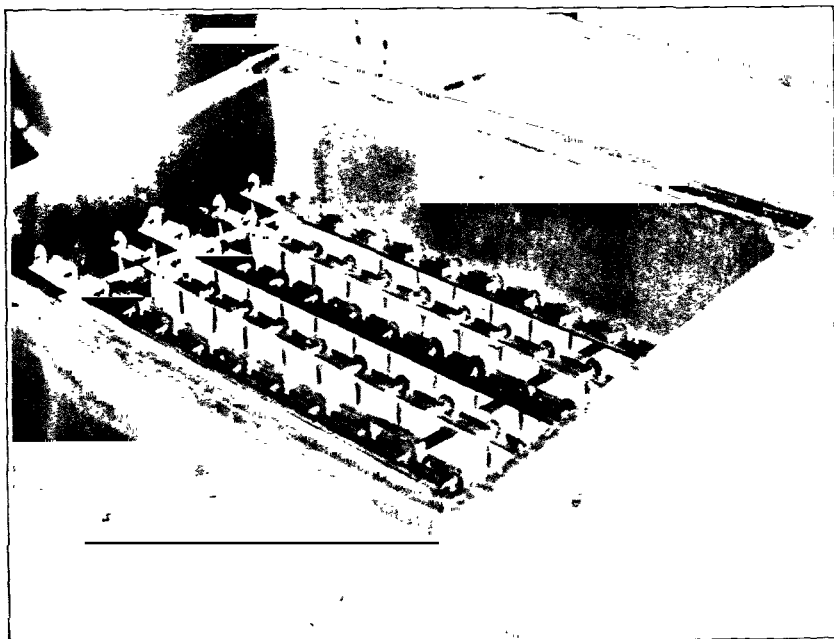
FIG. 9.—BUSS BARS AND HEADS OF DISCHARGE ELECTRODES IN PARTING-ROOM FLUE AT SELBY SMELTER.

FIG. 10.—ELECTRODES INSIDE OF PARTING-ROOM FLUE AT SELBY SMELTER.

FIRST COMMERCIAL INSTALLATIONS.

These experiments at Pinole attracted the attention of the Selby Smelting & Lead Co., whose smelter, located at Vallejo Junction, a few miles farther up the bay, was at that time the object of injunction proceedings brought by the farmers of the surrounding country. At the time the suits originated three separate stacks at the smelter contributed to the alleged nuisance. The first, and admittedly the most serious offender, handled the gases from the lead blast furnaces and discharged several tons of lead fume daily into the air. Shortly before the commencement of electrical precipitation work at the plant this had been obviated by the installation of the bag house,[1] shown in figure 8. After correcting this evil there still remained, however, a stack discharging the gases from the roasters, which, besides the invisible sulphur dioxide, furnished dense white clouds, consisting chiefly of sulphuric acid, arsenic, and lead salts, and to which the bag house was inapplicable on account of the corrosive action of these gases upon the bags. Lastly there was the stack of the refinery carrying the mists escaping from the pots of boiling sulphuric acid used to dissolve the silver out of the gold and silver alloy coming from the cupels.

The blast furnace and the roaster stacks each carried something over 50,000 cubic feet of gas per minute while the refinery stack represented scarcely a tenth of this volume. As a first step operations were accordingly commenced on this latter. and after several months' experimenting as to the best form of construction a system of vertical lead plates 4 inches wide by 4 feet in length and spaced about 4 inches apart was adopted. Several rows of such plates were assembled in a 4 by 4 foot lead flue. Between each pair of plates hung a lead-covered iron rod carrying the asbestos or mica discharge material, the latter finally proving the more serviceable in this highly acid atmosphere. These rods or discharge electrodes were supported on a gridwork of buss bars extending over the heads of the plates and through apertures in the sides of the flue to insulators on the outside. Figure 9 is a view looking down on the top of this flue with the cover removed from above the electrodes, and figure 10 is a view inside the flue looking through the system of electrodes. Figures 11 and 12 show the effect on the appearance of the stack when the electric circuit is respectively open and closed, the stack in the immediate left foreground being the one into which this flue discharges. The large stack in the middle background is from the roasters to be discussed below. Figure 13 shows the corresponding stream of dilute sulphuric acid (about 40° B.) running out from the flue as pre-

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[1] For detailed description see Eng. Min. Journ. vol. 86, pp. 451–457 (1908).

cipitated. When the acid kettles are at a full boil it often amounts to over 2 gallons a minute.

The electric current is taken from the power circuit of the plant at 460 volts, 60 cycles, and transformed up to 17,000 volts thence through the synchronous contact maker or rectifier to the electrode system. At first a glass-plate condenser was connected across the high potential line in parallel with the electrode system in order to assist in maintaining the potential of the electrodes between the intervals of contact, but was found troublesome and unnecessary in practice and in this and other installations is now omitted.

The power consumption for this installation is about 2 kilowatts, including the driving current for the synchronous motor, and the whole apparatus requires no more attention than a feed pump or a blower. This appears to have been the first commercially successful installation of electrical precipitation ever made, and has now been in regular daily operation for over seven years at a cost for labor attendance and repairs of less than $20 a month. In fact, while the plant was making enough bluestone to utilize all the weak acid recovered, the saving on purchase of the latter paid for the entire cost of operating five times over.

. In the seven years which have elapsed since this installation was made the processes have undergone steady development, and incidentally have passed through the many vicissitudes common to innovations in the industrial world. One of the first extensions of the work was naturally a series of experimental precipitation chambers in the main roaster flue of the same works. Two different forms of these are seen in figures 14 and 15. The former was of lead construction similar to that of the first installation but of some tenfold larger capacity, while the latter was of brick and iron construction and intended for the collection of drier and less highly acid-bearing material. Figures 16 and 17 show the 9-foot diameter brick stack discharging these gases with the electric current respectively off and on. Later, fundamental changes in the furnace equipment and metallurgical practice at this plant, obviated the need for electrical precipitation and the permanent installation originally contemplated for these particular flues has never been carried out.

OPERATIONS IN SHASTA COUNTY.

The installation next in order of size to be undertaken was at the Balaklala Smelter at Coram, Shasta County, Cal., 273 miles north of San Francisco on the main line of the Southern Pacific Railroad to Portland and Seattle. The vast body of low-grade copper ore reaching for many miles across this county and commonly known as the Copper Crescent, has been described in detail by L. C. Grafton [1]

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[1] U. S. Geological Survey, Bull., 430b.

PLATE 8.
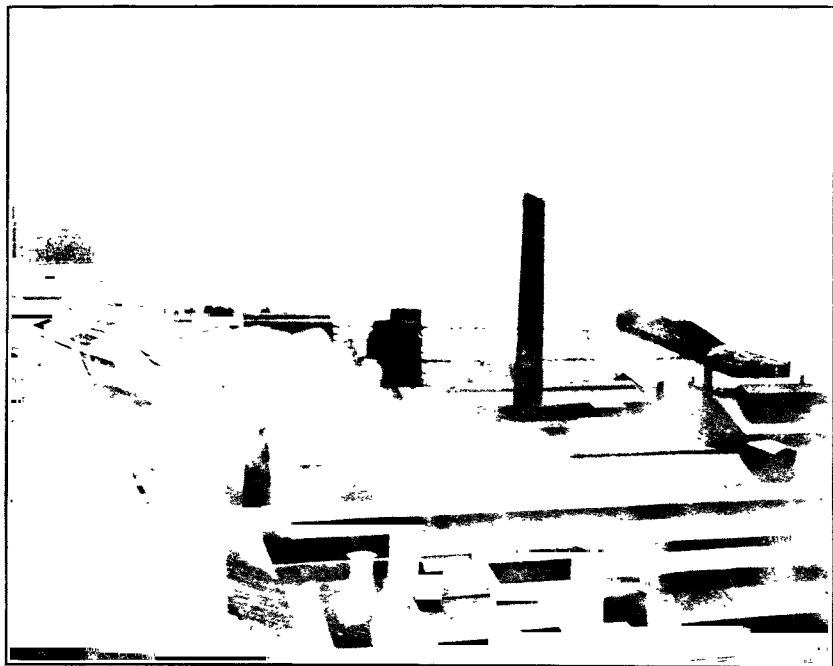
FIG. 11.—PARTING-ROOM STACK. SELBY SMELTER, ELECTRIC CURRENT OFF.
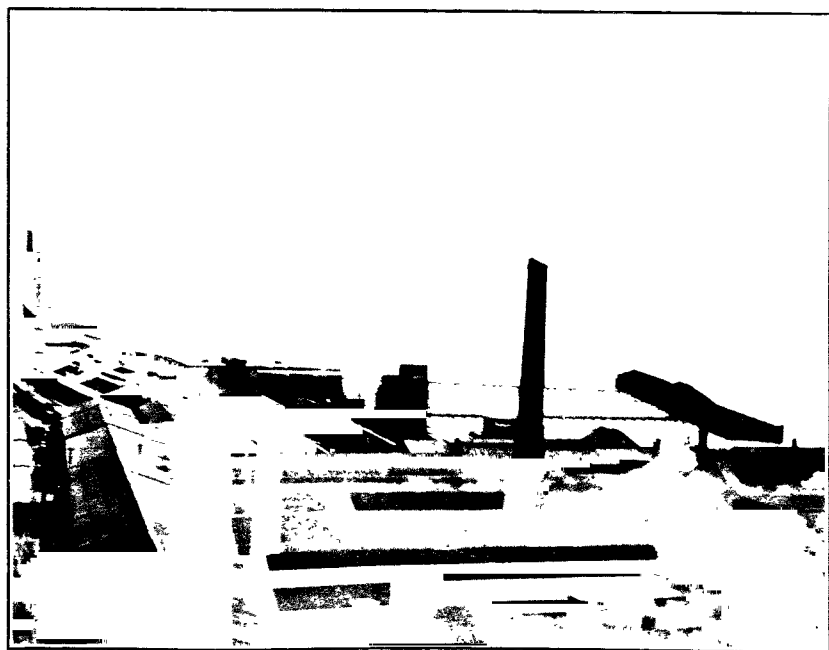
FIG 12.—PARTING-ROOM STACK. SELBY SMELTER, ELECTRIC CURRENT ON.

PLATE 9.

FIG. 14.—EXPERIMENTAL PRECIPITATOR IN LEAD FLUE FROM ROASTERS, SELBY SMELTER.
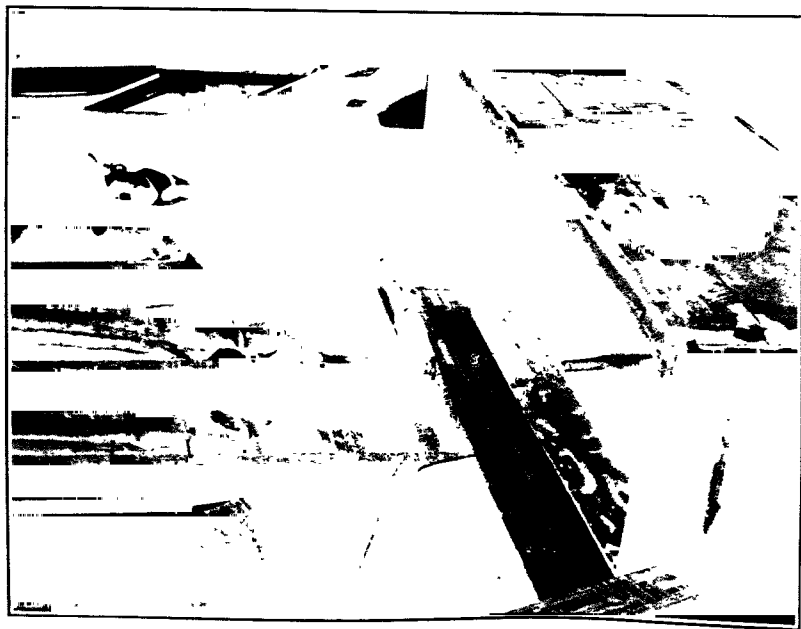
FIG. 13. ACID DISCHARGE FROM PARTING-ROOM PRECIPITATOR SELBY SMELTER.

PLATE 10.
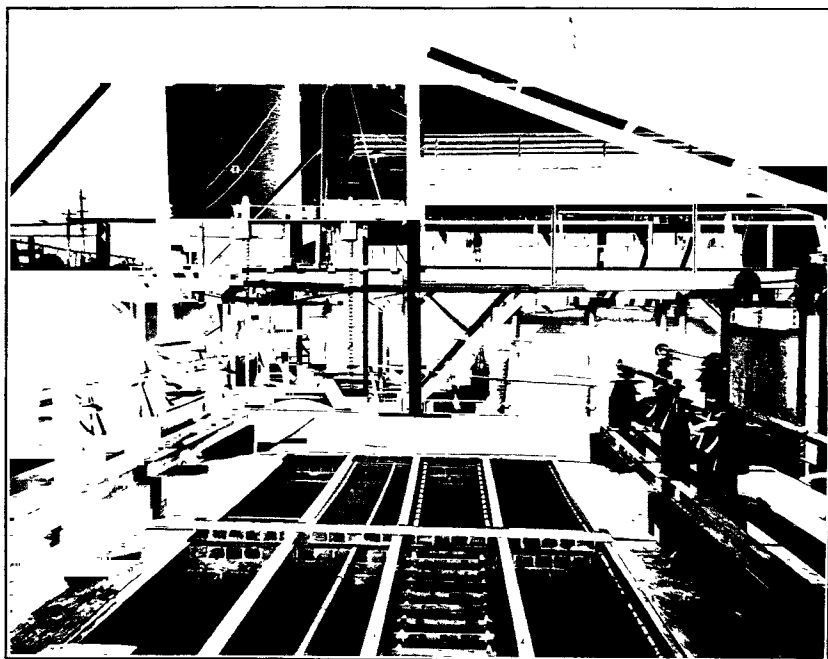
FIG. 15.—EXPERIMENTAL PRECIPITATORS IN BRICK FLUE FROM ROASTERS, SELBY SMELTER

PLATE 11.
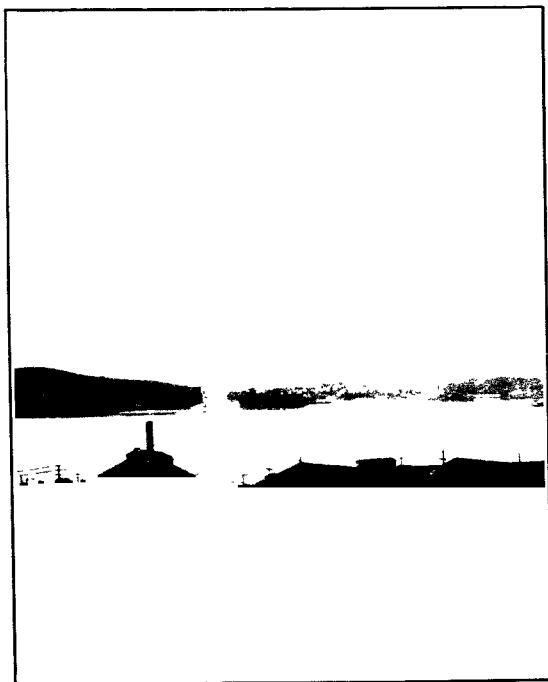
FIG. 16.—SELBY ROASTER STACK, ELECTRIC CURRENT OFF.
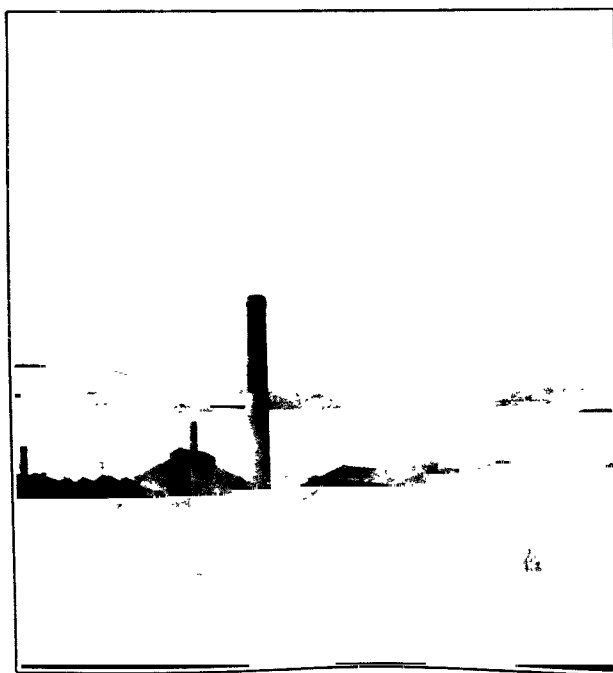
FIG. 17.—SELBY ROASTER STACK, ELECTRIC CURRENT ON.

and characterized as the second largest copper deposit which can be considered as a single geological unit in the United States. From the viewpoint of smelter smoke litigation this region has a particularly interesting history. Figure 18 shows by a rough sketch map the location of the principal features of interest for the present discussion.

The first commercially successful smelter in this region was erected at Keswick in 1896 by the Mountain Copper Co. (Ltd.), under the management of Louis T. Wright, and was of especial interest as one of the pioneers in pyritic smelting. Extensive heap roasting was also carried on at this plant with the result of widespread deforestation of the surrounding country and the final closing down of the plant in 1905 through injunction proceedings instituted
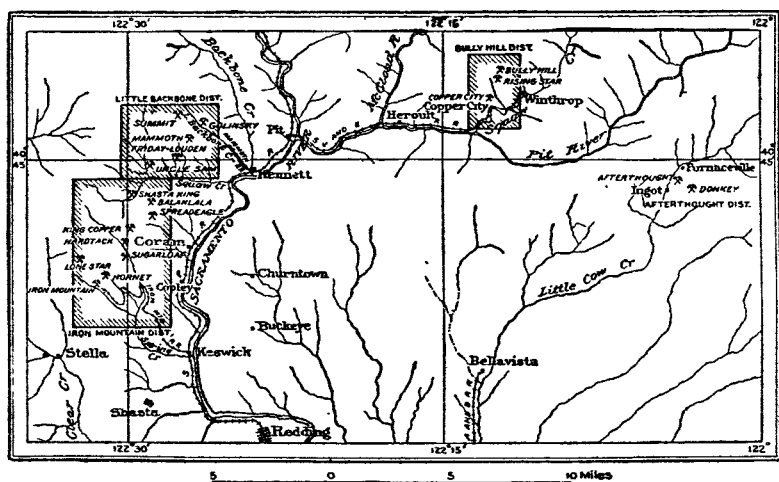
FIG. 18.—SKETCH MAP OF MINES AND SMELTERS OF SHASTA COUNTY, CALIFORNIA.

by the United States Forestry Service. The company has since built a small smelter and acid phosphate works at Martinez, on San Francisco Bay, and now ships its ore to this point, nearly 250 miles distant, for treatment, but even this latter plant has at various times come in for its share of fume litigation.

In 1901 the Bully Hill Smelter, at Delamar or Winthrop, with a capacity of 250 tons a day, was started. This was later purchased and is now owned by the General Electric Co., but since July, 1910, it has been closed as a result of complaints by the United States Forestry Service, who insisted at that time that the plant either close or at least commence efforts on a practical scale looking toward controlling its fumes.

In 1905 the Mammoth Copper Mining Co., a subsidiary of the United States Smelting, Refining & Mining Co., blew in its present

smelter at Kennett. This plant when running full has a capacity of some 1,200 tons of ore per day.

The Balaklala, or First National Copper Co., was the most recent of the Shasta County smelters, having blown in its first furnace in 1908.

These smelters are all situated in the narrow precipitous canyon of the upper Sacramento River and its tributary, the Pitt. The region itself is too steep and rocky for agriculture, but was once heavily wooded, although now swept bare of vegetation for miles. As far as the canyon itself is concerned, probably all the damage possible has already been done unless reforestation were undertaken. This latter even would probably be slow and difficult work, as since the loss of vegetation the steep hillsides have been washed bare of soil for miles around. At Redding, however, some 13 miles below Coram and 17 miles below Kennett, the canyon widens out into the fertile Sacramento Valley and from this point southward for some 12 miles farther lies the region from which came increasingly insistant complaints against the smelters. These culminated in the spring of 1910 in agreements between the farmers and the smelters under which friendly suits were brought in the Federal courts and injunctions issued by stipulation requiring the smelters to remove the suspended matter from their exit gases and dilute the latter to such an extent that their sulphur dioxide content should not exceed seventy-five hundredths of 1 per cent by volume as discharged from the stacks, with the further general and sweeping provision that they should do no damage.

To accomplish this the Mammoth Smelter installed a bag house, which has been in very successful operation since July, 1910. Figure 19 is a view of this plant showing the bag house on the left in operation. It will be noted that the gases discharged from the five stacks (each 21 feet square) are to all intents and purposes free from suspended matter and consequently invisible. This represents a notable achievement, being the first time that the bag house, so efficient in lead smelters, has been successfully applied to copper blast furnace gases on the large scale.

It is made possible in this instance through neutralization of the sulphuric acid in the gases by the zinc oxide carried over in the fume from the very heavy zinc content of the ore smelted. The company is also the owner of patents[1] on the introduction of finely divided metallic oxides into the gases for this purpose. In addition, it was necessary to provide an extensive system of cooling pipes, seen in

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[1] Clarence B. Sprague, U. S. Pats. 931515, Aug. 17, 1909, and 984498, Feb. 14, 1911. See also W. C. Ebaugh, Journ. Indus. and Eng. Chem., vol. 1, pp 686–689 (1909) and vol. 2, pp. 372–373 (1910). Also "Notes on Bag-Filtration Plants," by A. Eilers. Trans. Amer. Inst. Min. Eng., vol. 44, pp. 708–735 (1912).

PLATE 12.
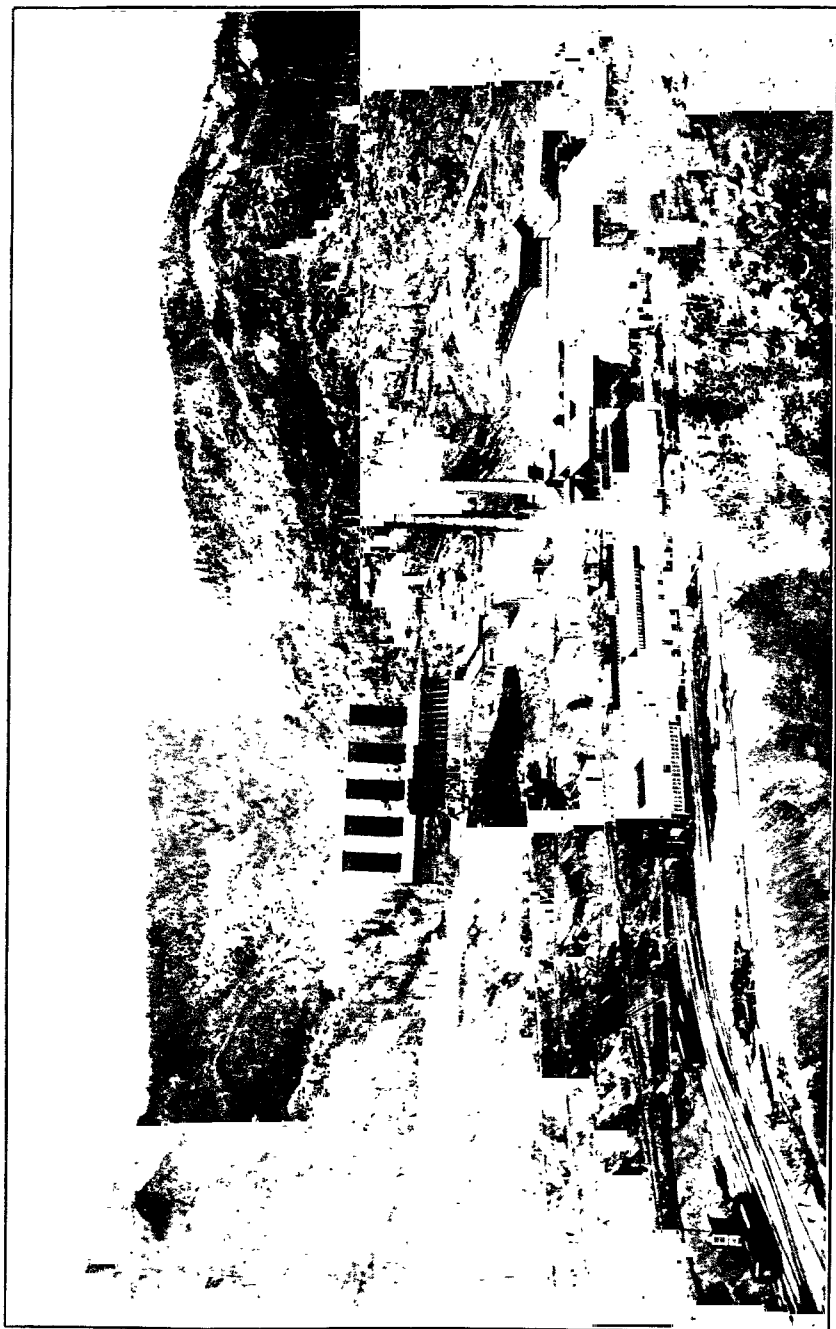
FIG. 19. SMELTER AND BAG HOUSE OF THE MAMMOTH COPPER MINING CO. AT KENNETT, CAL.

PLATE 13.
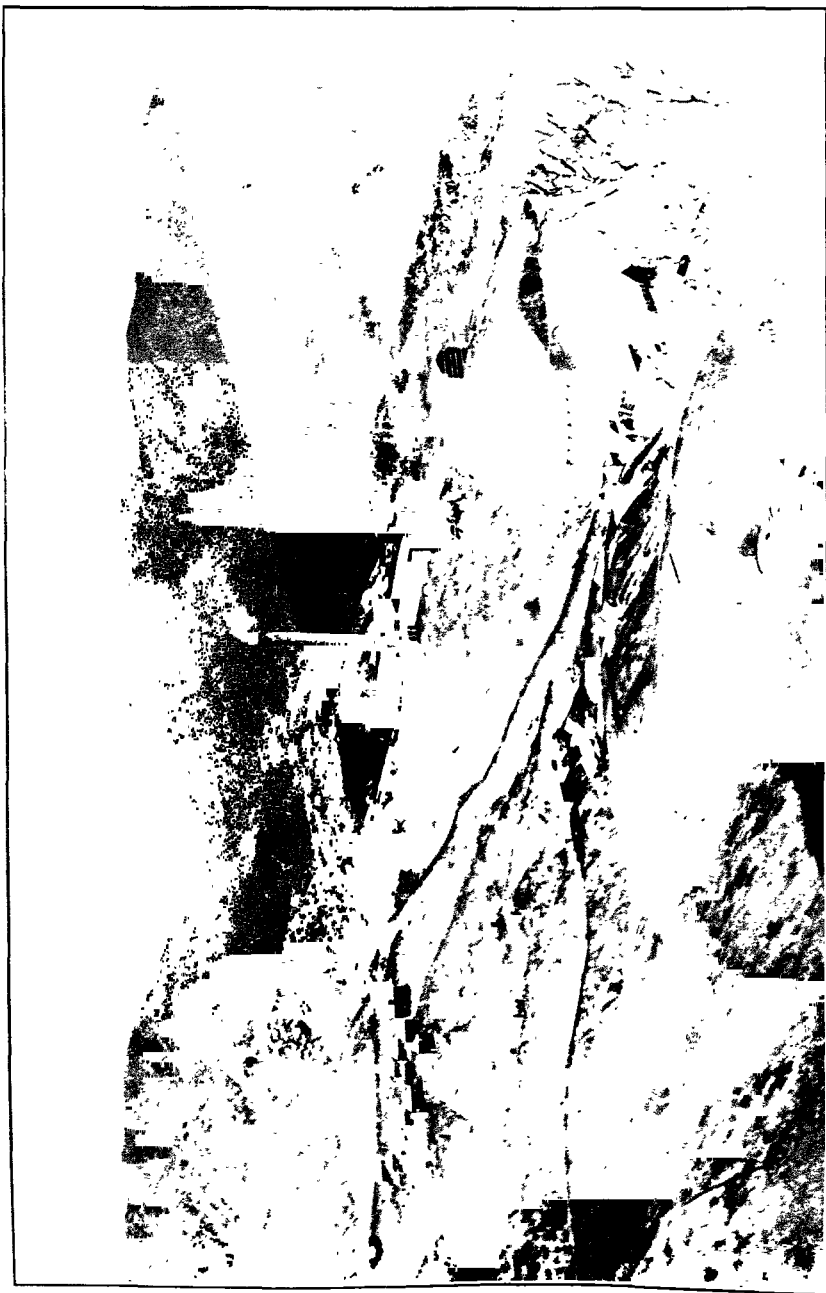
FIG. 20.—BALAKLALA SMELTER AT CORAM, CAL.

front of the bag house in the picture. There are 40 of these pipes, each 4 feet in diameter and averaging about 200 feet in length. They represent a very large part of the cost of the installation. It was expected that they would be sufficient to cool the entire gases of the plant to a safe temperature to protect the $30,000 worth of woolen bags with which the house is filled, but upon starting up with the gases passing through all the pipes in parallel it was found that only a little over half the full capacity of the plant could thus be treated with safety and operations were accordingly restricted to this. In the cold weather of winter a considerably larger tonnage can be handled with safety than during the hot summer. Subsequently by rearranging the pipe connections so as to have eight groups in parallel, each consisting of five pipes in series, the company succeeded in greatly increasing their efficiency as coolers, and thus materially increased the plant capacity over that first obtained. Provision was also made to supplement the pipe cooling by the blowing in of outdoor air when necessary. The fan power necessary to move all this vast weight of air and furnace gases through the bags and pipe system is of course considerable, reaching at times well up toward the 1,000-horsepower mark. Notwithstanding this, however, the bag house is to be considered a decided success, at least for the particular conditions met with at this plant, and the management deserves great credit for the courage and skill with which it has carried through this new and after all largely experimental undertaking, representing as it does the expenditure of over a quarter of a million dollars.

In the case of the Balaklala Smelter, of which figure 20 is a general view, the use of a bag house was also considered, and in fact a small experimental unit containing a few bags was run for some months in comparison with tests both by the electrical process here described and also a centrifugal apparatus in which the gases passed through a rapidly-rotating cylindrical shell equipped with radial baffles to insure the gas being raised to full velocity. As a result of these tests the electrical process was adopted for the full-sized installation.

The smelter was treating from 700 to 1,000 tons of $2\frac{1}{2}$ to 3 per cent ore carrying over 30 per cent of sulphur with considerable but varying amounts of zinc, the greater proportion of this being handled in blast furnaces, but the fines including everything under an inch and amounting to less than 10 per cent of the whole going through MacDougal roasters and an oil-fired reverberatory. The plant has also two converter stands. The gases from all these departments passed into a common flue 18 by 20 feet in cross section, an interior view of which at the main by-pass damper is shown in figure 21. The volume of gases passing through this flue varied with operating conditions from a quarter to half a million cubic feet a minute, which

means, in round numbers, a mean linear velocity in the flue shown of 10 to 20 feet per second.

Before attempting to design the full-sized equipment for treating these gases a small precipitation chamber capable of treating about 1 per cent of the total gases was erected and an extended set of experiments made with it. Figure 22 shows this small unit with its exhaust fan and stack. In the original tests it was located nearer the base of the main stock, the figure showing it as later modified for other experiments and tests.

Figures 23 and 24 indicate the degree of success attained with this small unit in its original position, having been taken a few minutes apart with the electric current respectively off and on, the same gas volume issuing in both instances from the stack, which is 2 feet in diameter.

With this miniature unit as a guide, the equipment of the whole plant with similar apparatus was undertaken in March, 1910. This was completed and first put into operation the end of the following September, and with the exception of a couple of weeks in December, remained in continuous operation until July 24, 1911, when the whole plant shut down until such time as a practical method could be found for removing from the gases not only the suspended solids, but the sulphur dioxide gas as well. Experiments to this end with the Hall process already referred to, upon at least a semicommercial scale, have since been pursued by the Balaklala Co. at the smelter; but no decision seems yet to have been reached regarding their commercial practicability on the full-sized operating scale of the smelter. These experiments on sulphur dioxide have, however, nothing fundamentally to do with the electrical precipitation, and returning to this it may be said that the nine months of operation which the plant had amply demonstrated the entire practicability of extension of the process to operation of this and even larger scale.

As was naturally to be expected many difficulties were encountered, some of which were quickly overcome, while others gave way more gradually before the systematic study of operating conditions.

Figure 25 is a plan of the nine electrical precipitation units or chambers in their relation to the flue system and stack. It should here be noted that the two large fans indicated in the drawing were not required for the operation of the precipitating system nor to overcome any resistance due to its introduction, as this latter was very slight indeed. The fans were made necessary by that section of the court's decree requiring dilution of the sulphur dioxide to three-quarters of one per cent or less. When the furnaces were running on a high sulphur charge this feature of the decree necessitated a considerable dilution of the gases with fresh air and corresponding diminution of stack draft. At such times the fans were operated, but during

PLATE 14.
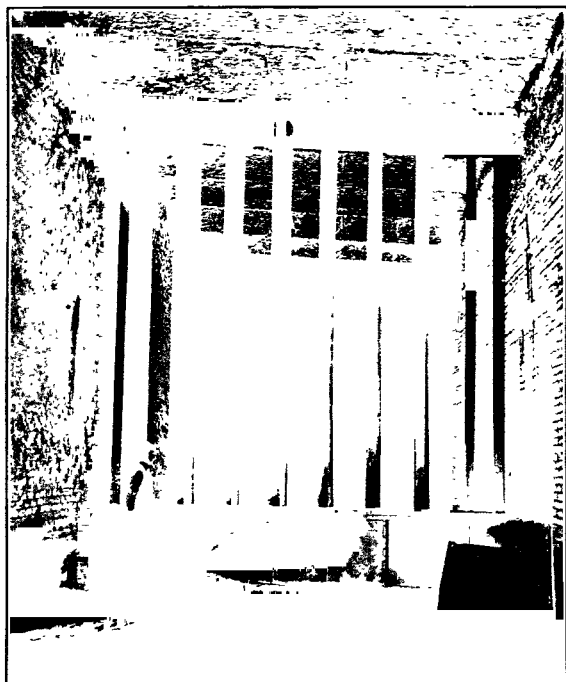
FIG. 21.—DAMPER IN MAIN FLUE OF BALAKLALA SMELTER.
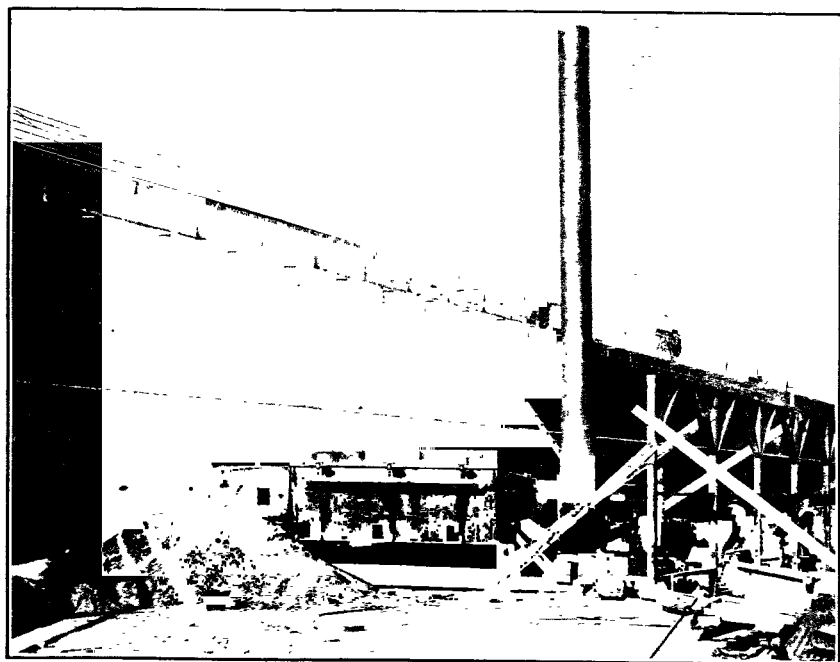
FIG. 22.—MAIN FLUE, STACK, AND EXPERIMENTAL PRECIPITATOR AT BALAKLALA SMELTER.

PLATE 15.
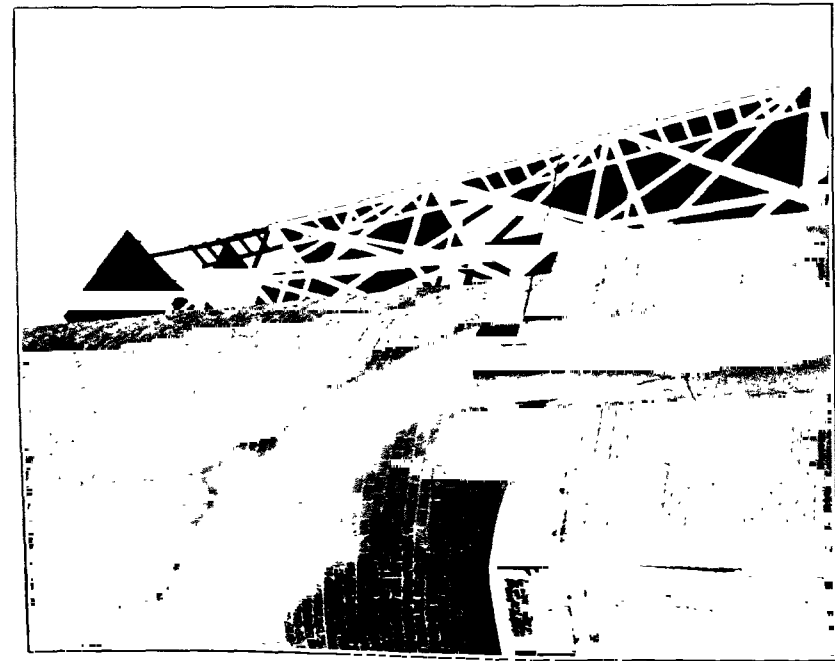
FIG 23.—DISCHARGE FROM EXPERIMENTAL PRECIPITATOR AT BALAKLALA SMELTER, ELECTRIC CURRENT OFF.
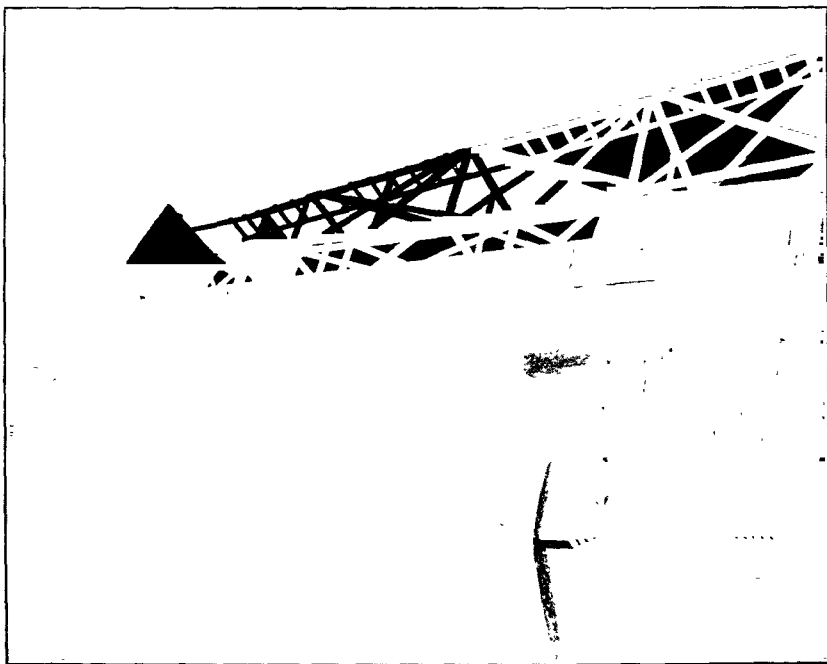
FIG 24.—DISCHARGE FROM EXPERIMENTAL PRECIPITATOR AT BALAKLALA SMELTER, ELECTRIC CURRENT ON

PLATE 16.

FROM BLAST FURNACES
REVERBERATORY AND CONVERTERS

FROM ROASTER

40'-6"

9

8

7

6

5

4

3

2

1

INLET FLUE

OUTLET FLUE

16'-0"

DAMPER

300 P MOTOR

180' FAN

180' FAN

300 P MOTOR

STACK 250' x 18'

RECTIFIER BLDG. 36x78'

RECTIFIERS

RECTIFIERS

SWITCHBOARD

TRANSFORMERS
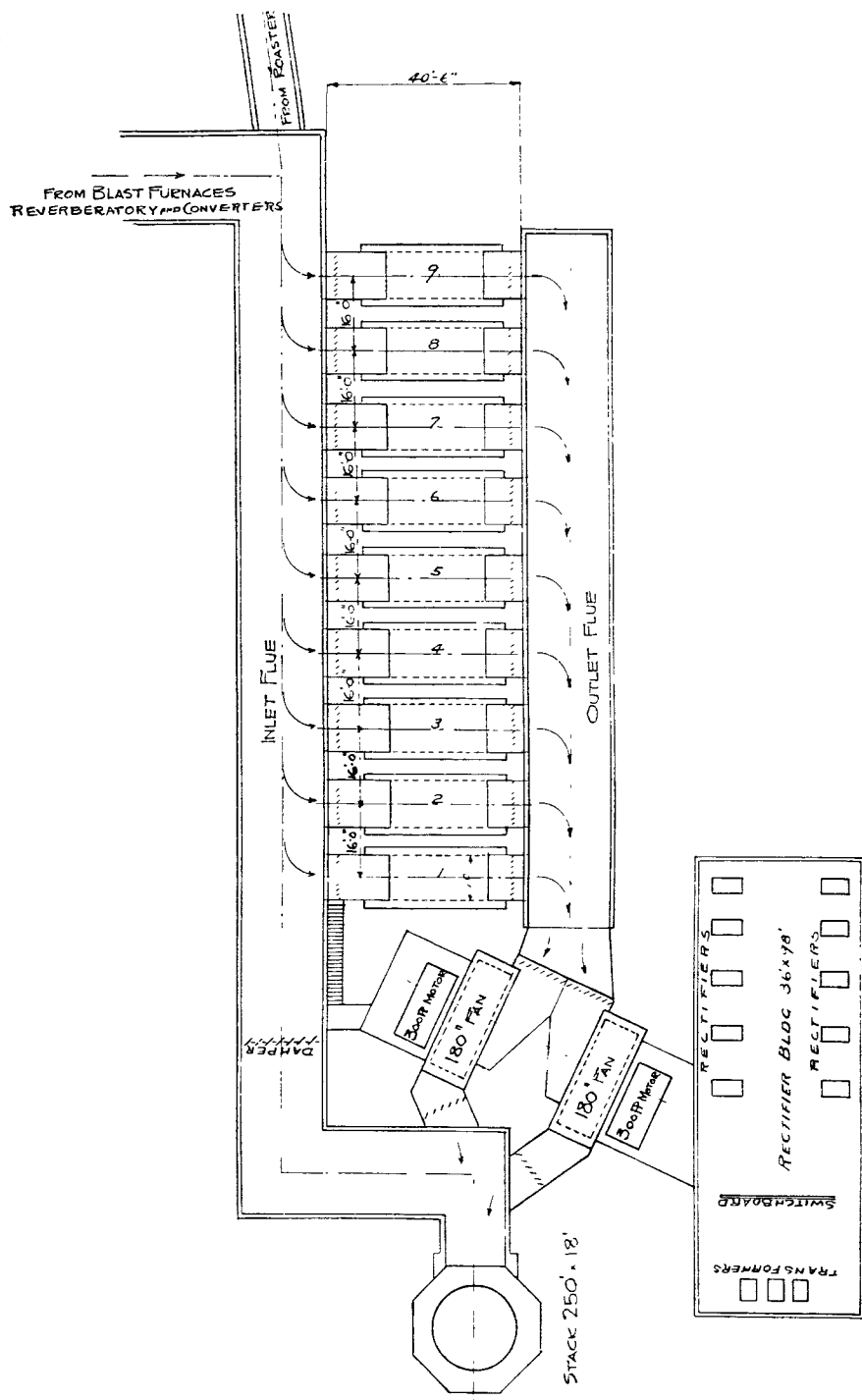
FIG. 25.—GENERAL ARRANGEMENT OF PRECIPITATION PLANT, BALAKLALA CON. COPPER CO., CORAM, CAL.

PLATE 17.

FUME HOPPER

SECTION THROUGH
PRECIPITATING UNIT
BALAKLALA CON COPPER CO
CORAM CAL
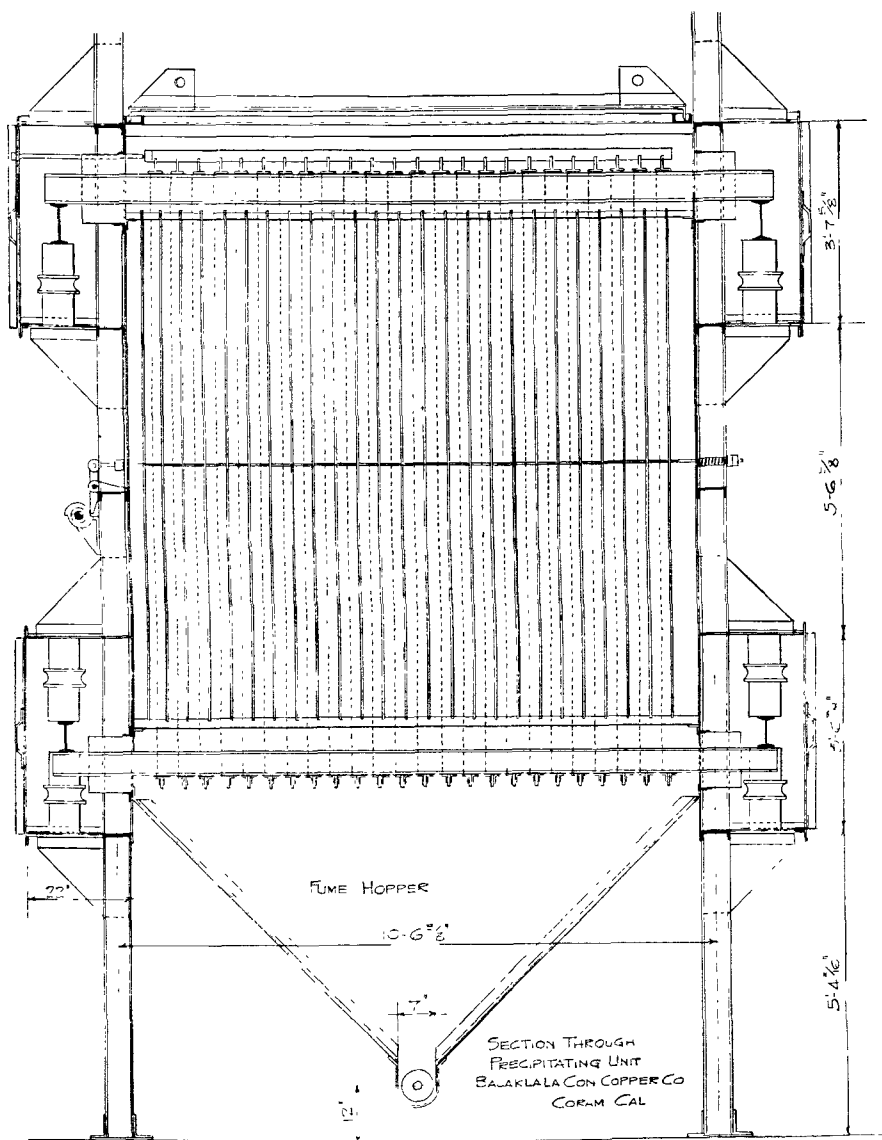
FIG. 26.—PRECIPITATING UNIT, BALAKLALA CON. COPPER CO, CORAM, CAL.

a considerable portion of the time the sulphur dioxide in the gases could be brought low enough without interference with the draft, and during these periods the fans were stopped entirely, although the gases still passed through them.

At the rectifier building the current was received from the company's three-phase power circuit at 2,300 volts, 60 cycles, and after being transformed up to from 25,000 to 30,000 volts under the control of the operator through variable resistance and induction regulators was rectified into an intermittent direct current, as already explained, and distributed to the individual precipitating units.

Figure 26 shows a cross section through one of these units or precipitating flues as first installed, and although forms of construction have been greatly modified and improved in later installations, this view still clearly illustrates the fundamentals of the method. The double vertical lines represent the collecting or grounded electrodes, each 6 inches wide by 10 feet high, made of No. 10 sheet iron. The dotted lines represent the discharge electrodes, consisting of two iron-wire strands between which was twisted the discharge material, for which both asbestos and mica preparations were at various times used in this plant. Each unit contained 24 rows of 24 electrodes of each type. The collecting electrodes were carried by bars connected directly to the frame of the chambers themselves, while the discharge electrodes were spanned by springs between a system of buss bars carried on externally placed insulators, as shown in the figure. To the auxiliary chambers surrounding these insulators a small regulated amount of air was admitted to prevent conductive dust or fume from working back and settling on the insulators.

The cam and shaker rod extending across the middle of the unit was originally designed for the purpose of vigorously shaking the electrodes, as it was greatly feared that the removal of precipitate from the electrodes in units of this size might be one of the most serious problems. In actual operation it was found, however, that the electrodes could easily be shaken by hand from the top entirely free from dust, the whole operation including cutting the unit in and out of the system and the removal and replacement of its covers, requiring only about 10 minutes, this having to be repeated every six or eight hours, depending on the dust content of the gases. The precipitated dust and fume as it fell from the electrodes was carried by the conveyor in each unit to a common longitudinal conveyor, which in turn discharged into cars carrying it away for treatment and recovery of its values.

Figure 27 is the interior of the rectifier house or control station, showing the general arrangement of the apparatus and wiring. Figure 28 shows the precipitation units in course of construction, while figure 29 is a view over the tops of six out of the nine units

after completion. Figures 30 and 31 are photographs of the main stack taken a few minutes apart, with the electric current respectively off and on.

Filtration tests upon the gases before and after the electrical treatment throughout the nine months of operation showed that this plant under favorable working conditions precipitated between 80 and 90 per cent of the suspended matter in the gas, the average over the whole period of operation being somewhat less, while after introducing improvements in detail of construction on one of the units shortly before the final shutdown of the plant the efficiency of this unit was carried well up into the nineties. Under average operating conditions at the smelter some 6 to 8 tons of precipitate were collected per 24 hours. Figure 32 shows this steady stream of precipitated smoke as it flowed night and day from the end of the conveyor coming from the units, and figure 33 shows the stock pile of several hundred tons of this as it collected below the discharge.

The gas-treating plant as a whole, including flues, fans, motors, and electrical apparatus, cost, up to the time it was first put in operation, a little less than $110,000. Although many minor changes were later made, none of the larger or more expensive elements of construction were greatly altered.

The total average power consumption for the precipitation plant was in the neighborhood of 120 kw. One man could readily control the whole operation in the rectifier house, although as a matter of precaution for a new plant under the high tension here used, two were usually on duty. Two laborers and a foreman were employed on the precipitating units and dust-handling system, although this could have been reduced somewhat by automatic shaking devices, as in the Riverside Plant described below.

The volume of gases treated varied considerably with the conditions at the furnaces, but may fairly be taken as averaging between 200,000 and 300,000 cubic feet per minute. and entering the units at from 100° to 150° C.

WORK AT OTHER WESTERN SMELTERS.

This plant, while not able to save the Balaklala smelter from an eventual shutdown, formed a very important link in the development of the processes to their present status. The interest of the smelter companies up to this point depended almost entirely on the hope of eliminating smoke as a nuisance and its attendant litigation with their neighbors; and had it not been for the life or death struggle that this meant to them, it is probable that the success of the electrical processes might have been delayed many years longer. Once brought, however, under this powerful stimulus to the state of development above described. the importance of these processes for the

PLATE 18.
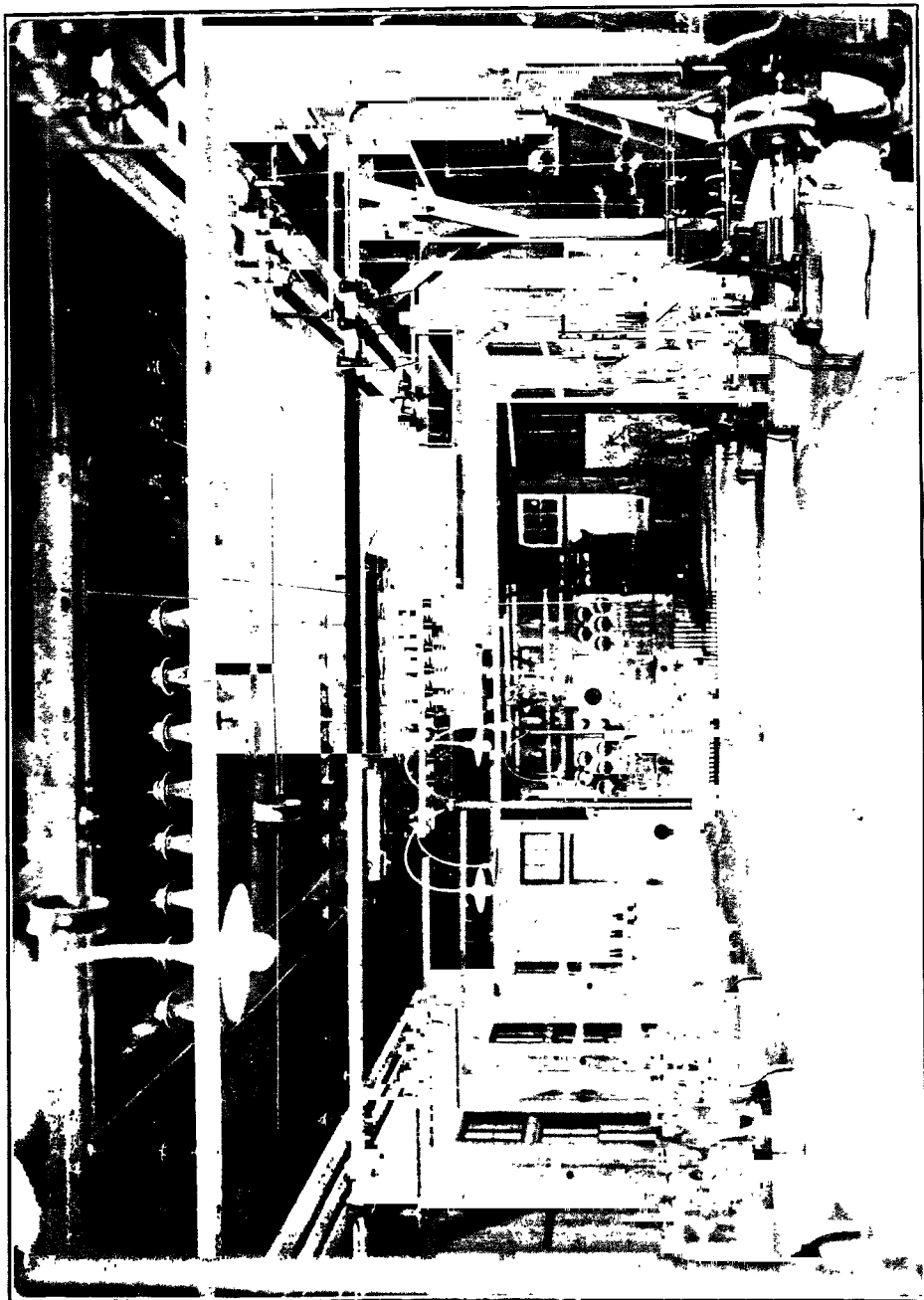
FIG. 27. CENTRAL CONTROL STATION OF PRECIPITATION PLANT AT BALAKLALA SMELTER.
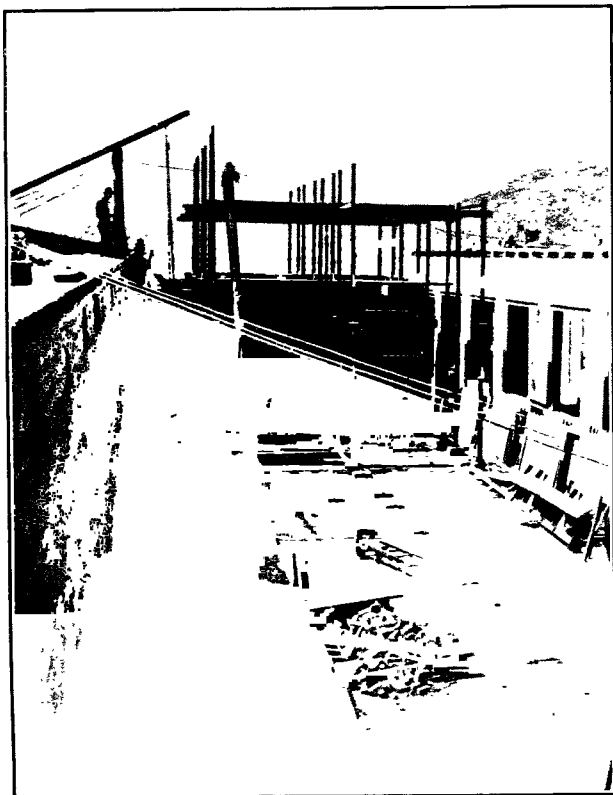
FIG. 28.—CONSTRUCTION OF PRECIPITATION CHAMBERS AT
BALAKLALA SMELTER.
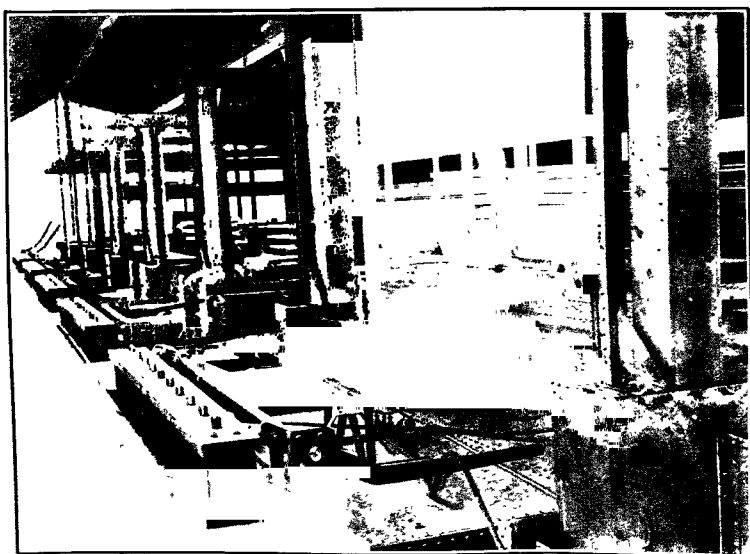
FIG. 29.—VIEW ACROSS PRECIPITATION CHAMBERS AT BALAKLALA SMELTER.

PLATE 20.
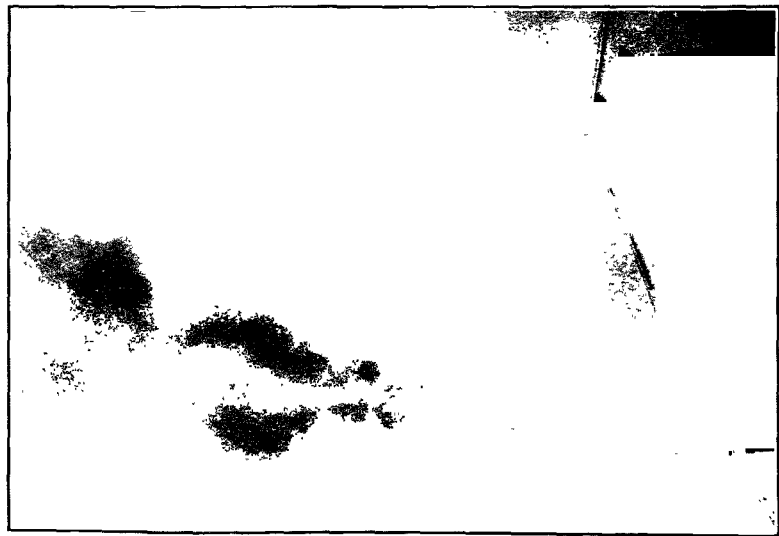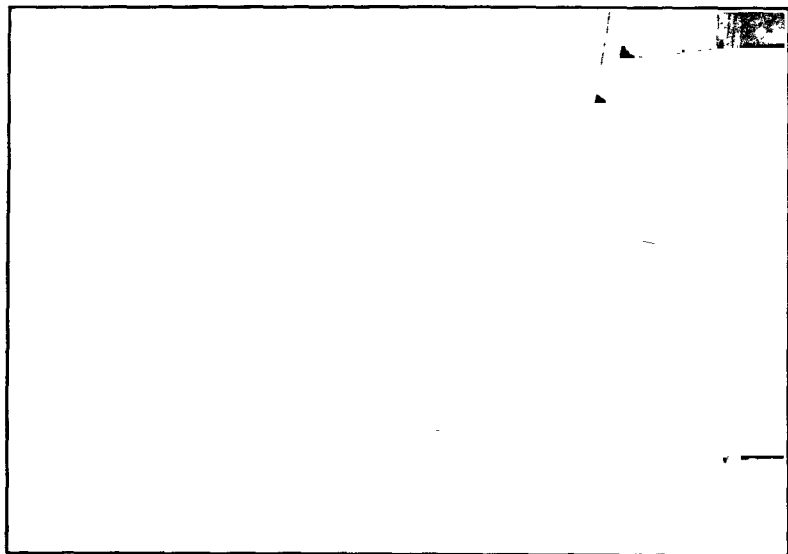
FIG. 31. — MAIN STACK, BALAKLALA SMELTER, ELECTRIC CURRENT ON

FIG. 30. MAIN STACK, BALAKLALA SMELTER, ELECTRIC CURRENT OFF.

PLATE 21.

FIG. 33.—STOCK PILE OF SEVERAL HUNDRED TONS OF PRECIPITATED SMOKE, BALAKLALA SMELTER.

FIG. 32.—CONVEYOR DISCHARGING PRECIPITATED SMOKE, BALAKLALA SMELTER

saving of values lost through waste gases began to claim general interest, and at present a large number of precipitating plants are under construction and several are already operating in copper, lead, and iron smelters, metal refineries, cement mills, and a varied set of chemical industries.

It is unnecessary here to describe any of these plants in great detail as they represent essentially the same principles as those already discussed, but the accompanying illustrations may serve to give an idea of the present trend of the subject.

Figures 34 and 35 show current on and off in an experimental unit erected about the end of 1911 at the Garfield copper smelter in Utah to treat the gases from basic lined converters handling a copper matte carrying a small percentage of lead. In this case 5-inch steel pipes carrying the gases acted also as grounded or collecting electrodes, the discharge electrodes being wires stretched axially within them. The deposited material was shaken down from time to time by striking the pipes with a system of hammers attached to the rocking shafts seen in the picture passing behind the front row of pipes. A pile of this deposit, consisting chiefly of basic lead sulphate, carrying gold, silver, and other values is seen on the ground to the right. This unit consisted of 24 pipes and was followed by another one of 600 pipes, which was successfully operated for about a month on steady tests taking the whole of the gas from one large basic converter and part of the time a part of that from another one as well. A part of this equipment was then moved to a point where gases from the other departments—that is, blast furnaces, reverberatories, and roasters—could also be secured, and experiments continued on each of these and on mixture of them. They were all found to be easily handled. The others in fact even more easily than the converter gases shown above, but these latter contained the highest values. This installation is seen in figure 36, the small building to the right containing the transformer and rectifier, while one of the large catenary flues appears in the background. Having determined to build a new flue system and dust chamber for the blast furnace and converter gases at Garfield, it was decided to incorporate an electrical precipitation plant for the treatment of all the converter fumes. This entire project is now under construction, and in the planning of this flue system provision has also been made for the installation of an electrical precipitation plant for the treatment of blast furnace gases, should it later be decided to do so. The precipitation plant for the converter gases is expected to be in operation by fall of this year.[1]

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[1] " Electrical Fume Precipitation at Garfield," by W. H. Howard. Paper presented at Salt Lake meeting Amer. Inst. Min. Eng. Aug. 11, 1914, and later to appear in the Transactions.

Another installation to treat about 100,000 cubic feet of gas per minute and consisting of 384 pipes, each 13 inches in diameter, is also under construction at the lead smelter of the Consolidated Mining & Smelting Co. at Trail, British Columbia.

Another unit of tubular type is seen in figure 37. In this case the pipes are of lead 12 inches in diameter and 12 feet long. This unit was constructed at Anaconda to collect the copper and acids volatilized from an 80-ton experimental MacDougall furnace, roasting low-grade sulphide tailings with salt preparatory to leaching.[1] Figures 38 and 39 are the same, with the electric circuit of some 60,000 volts, respectively, off and on.

Where the material collected is largely liquid or saturated with acid, as in this case, both wood stave and vitrified terra-cotta pipes up to 2 feet in diameter have also been used with success, and with dry material iron-pipe construction has been successfully employed up to 36 inches diameter and 20 feet in length. In these larger pipes several discharge electrodes are sometimes employed, carried on a central support.

This type of construction, where applicable, has done much to simplify and reduce cost of installation.

ELECTRICAL PRECIPITATION AND GASEOUS CONSTITUENTS.

The electrical process, it must be remembered, precipitates only suspended particles, be they liquid or solid, but does not in itself extract any of the truly gaseous constituents of the mixture under treatment. What is gas under one set of conditions may, however, be solid or liquid under others. Thus recent experiments upon arsenic-refining furnaces at Anaconda have indicated the practicability of installing two precipitating units in series, the first treating the hot gases as they come directly from the furnaces roasting crude flue dust, their temperature at this point being so high that the arsenic is for the most part in the form of true gas, and only the nonvolatile dust mechanically carried over by the draft is precipitated. Beyond this unit the gases are cooled by admixture of cold air, and the arsenic separates as a cloud of solid fume, which is then precipitated in a state of high purity in the second electrical precipitation.

This principle might, of course, also be applied in a greater number of stages to mixtures of materials of different volatilities and in this way opens up new possibilities for the application of fractional distillation and condensation.

Another indirect method of removing a particular gaseous constituent from a mixture by the electrical processes is illustrated by

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[1] "Roasting and Leaching Tailings at Anaconda, Mont.," by Frederick Laist, Bull. Amer. Inst. Min. Eng., vol 79, pp. 1147–1162, July, 1913.

FIG. 34.—EXPERIMENTAL PRECIPITATOR AT CONVERTER PLANT, GARFIELD SMELTER, ELECTRIC CURRENT OFF.
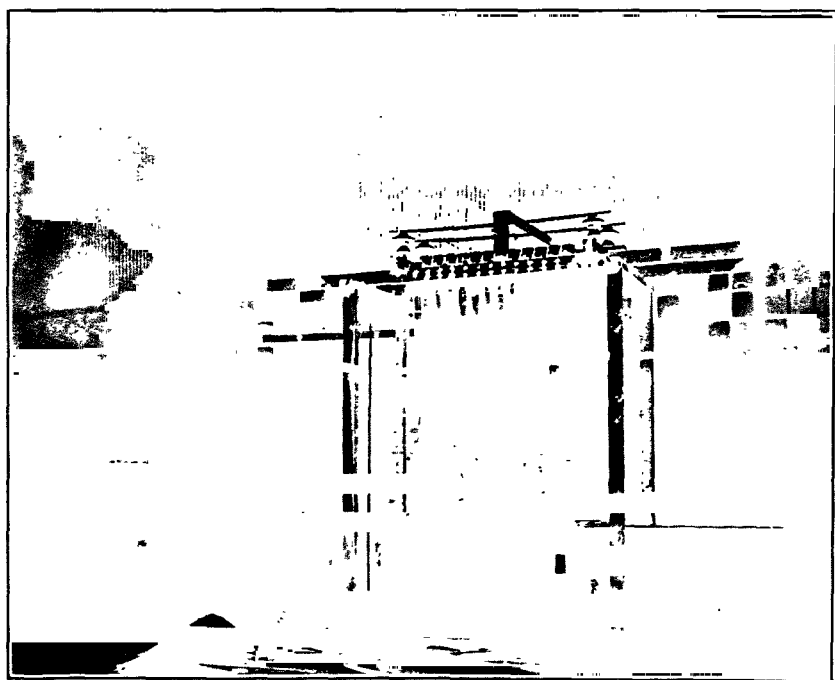
FIG. 35.—EXPERIMENTAL PRECIPITATOR AT CONVERTER PLANT, GARFIELD SMELTER, ELECTRIC CURRENT ON.
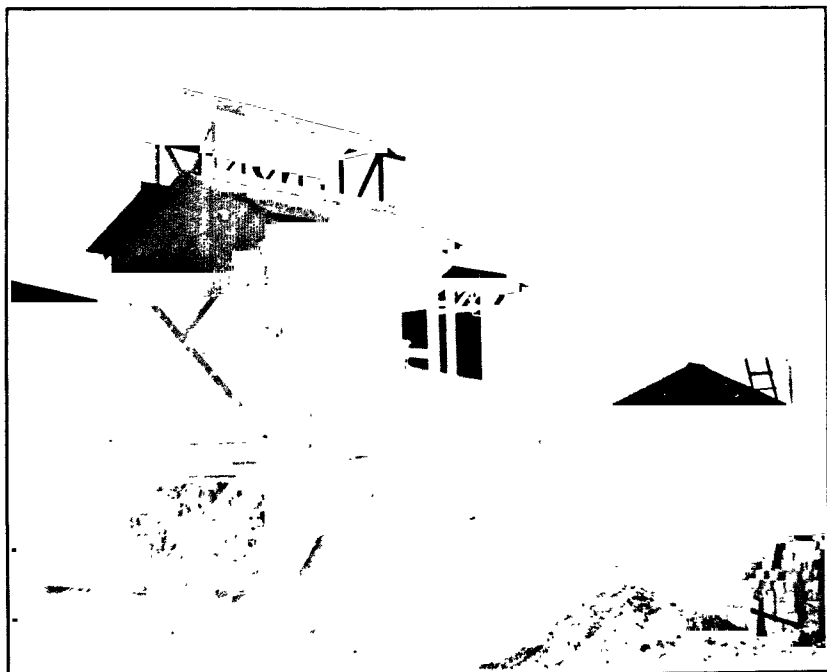
FIG. 36.—EXPERIMENTAL PRECIPITATOR ON MAIN FLUES, GARFIELD SMELTER.
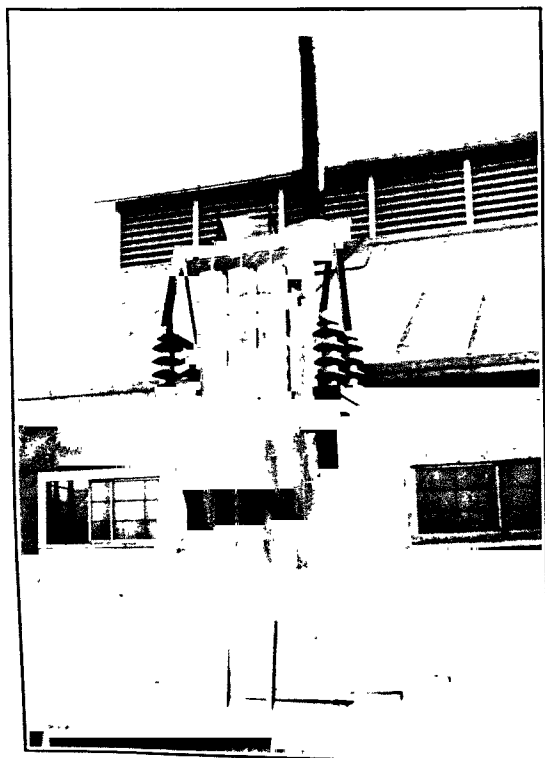
FIG. 37 —PRECIPITATOR ON ROASTER FLUE OF EXPERIMENTAL
LEACHING PLANT, ANACONDA, MONT.
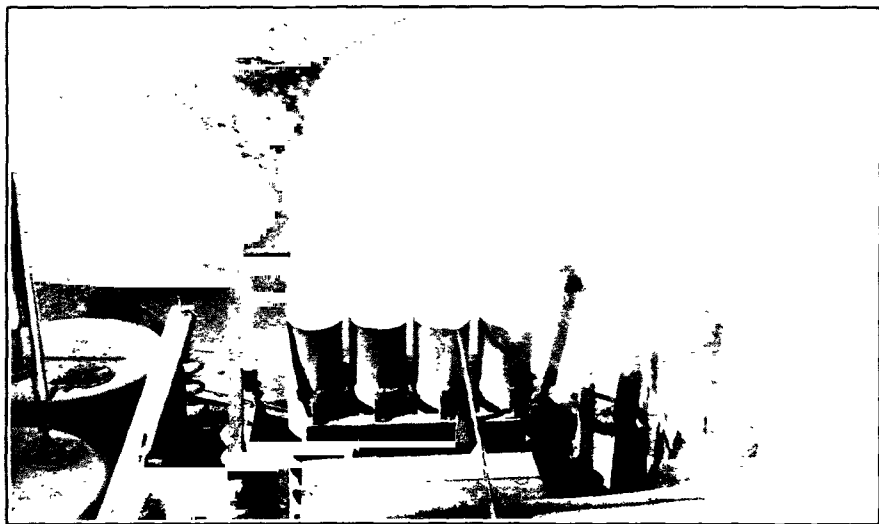
FIG. 38.—DISCHARGE FROM ANACONDA LEACHING PLANT PRECIPITATOR, ELECTRIC
CURRENT OFF.

FIG. 39.—DISCHARGE FROM ANACONDA LEACHING PLANT PRECIPITATOR, ELECTRIC
CURRENT ON.

PLATE 25.
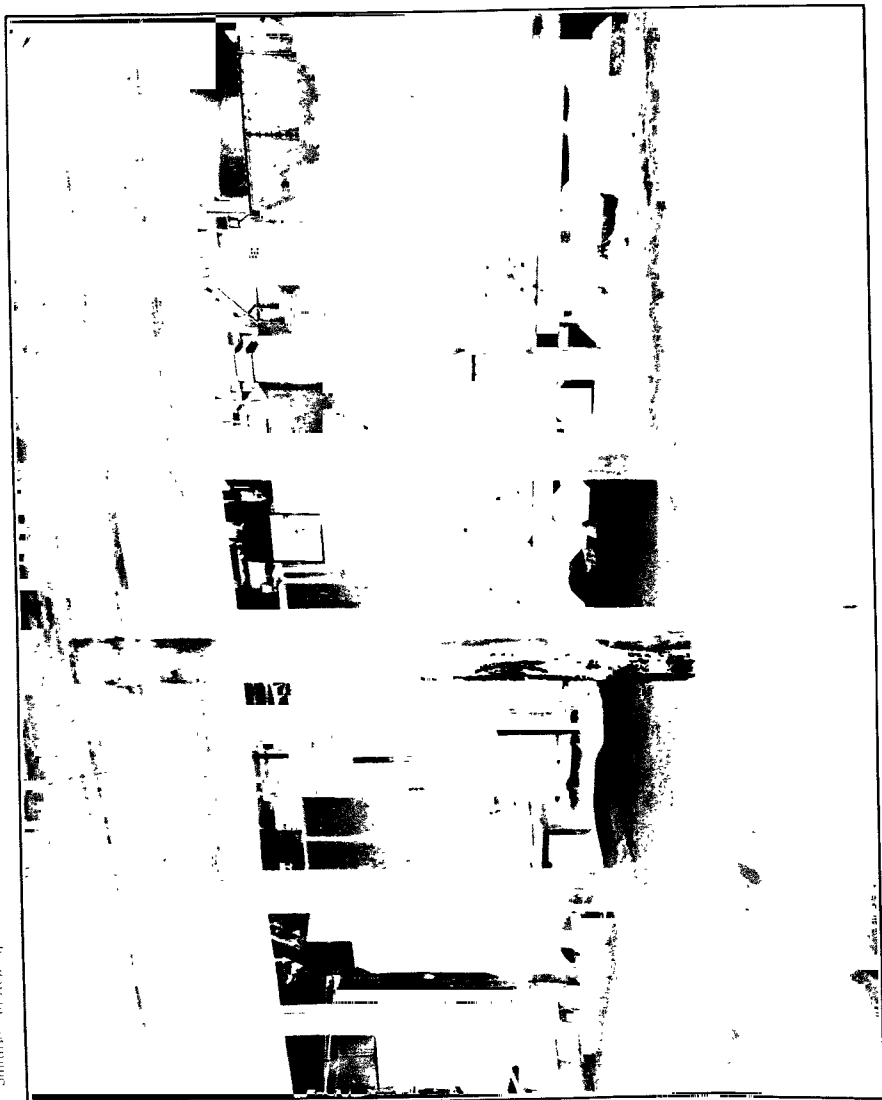
FIG. 40.—PRECIPITATOR AT HOOKER ELECTROCHEMICAL CO., SHOWING INSULATOR SYSTEM.

an installation now in operation at the Hooker Electrochemical Co., Niagara Falls, where the exit gases of the chloride of lime factory are freed from their last traces of chlorine by first blowing into them as they travel along finely divided slaked lime and a little farther down the flue recovering this again by the precipitation unit shown in figures 40 and 41. Although the lime thus remains in the gases only a few seconds, it is in such a fine state of subdivision that absorption is complete and the gases leave the treater without a trace of odor.

Still another application, which in a sense is almost the reverse of this procedure, has been worked out in connection with the drying of solutions and emulsions, such as milk and other unstable material, by atomizing them in a fine spray into warm dry air and collecting by electrical precipitation the fine dry powder left by the evaporation of the microscopic droplets as they float along.

ELECTRICAL PRECIPITATION AND ORDINARY COAL SMOKE.

As to the relation of electrical precipitation to the problem of ordinary coal smoke, it has already been pointed out in the early portion of this article that the most general solution of the coal-smoke problem lies in better combustion, and that what is here needed is not so much a method for collecting smoke as one for preventing its original formation. However, for some time to come, and, in some special cases perhaps permanently, precipitation methods may prove a stepping stone and useful adjunct. For example, in power plants having a high peak load, i. e., a very high power demand for a short period of the day as compared with the remainder of the time it is often impracticable to operate over this peak load without producing some black smoke unless a much larger furnace and boiler equipment is installed than is required for the average load. In such cases the installation and operation of precipitation apparatus to take care of this peak-load interval may prove more economic than that of the addition of boilers and furnaces otherwise required. The locomotive smoke from railroad round-houses seems another legitimate field until electrification of steam roads in cities shall become more general. Again there are the stacks of certain furnaces in steel works where for metallurgical purposes it has become established procedure (even though we may question the absolute necessity) to carry a smoky flame for insuring a reducing atmosphere.

The electrical treatment of this kind of smoke presents little new in the way of difficulties from the technical side save in the mechanical details of removing the light fluffy soot from the electrodes after deposition. Figures 42 and 43 show two installations for this

purpose, the first upon the discharge from the checker brick super-heaters in a western gas works where gas for household use is generated by the decomposition of crude petroleum, and the second a precipitation unit installed on the flue from an 80-horsepower boiler at the United States Bureau of Mines Fuel Experiment Station, in Pittsburgh. Figures 44 and 45 show the effect upon the appearance of the stack from this latter unit produced by switching the electric current off and on while carrying a badly smoking soft coal fire in the furnace.

In this connection should also be mentioned the work of the late Dr. Robert Kennedy Duncan and his associates, in the Mellon Institute of Industrial Research, at the University of Pittsburgh. To Dr. Duncan is due in a very large measure the credit for bringing to public notice in a practical form the possibilities and importance of more systematic and effective cooperation between the academic and industrial agencies of the country. As a part of the system of industrial fellowships which he had built up[1] and in whose further development he was actively engaged at the time of his death, was one group of problems centering about the smoke nuisance with somewhat more special reference to conditions in Pittsburgh.

Through the public spirited interest and generosity of the Mellon family of that city, these smoke investigations were enabled to assume a very comprehensive scope, several valuable bulletins[2] having already been issued as a result. As Prof. Duncan had the good fortune to see his dreams grow to a permanent foundation in his lifetime we may look forward to further results of ever growing usefulness from this source.

Among the various aspects of the smoke problem which received attention at the Mellon Institute was that of electrical precipitation, and as a result several papers by Dr. W. W. Strong, one of the fellows,[3] bearing particularly upon the theory of the processes, have since appeared, together with patents,[4] upon smoke indicators and recorders involving these principles.

[1] On certain Problems Connected with the Present-Day Relations Between Chemistry and Manufacture in America, by Robert Kennedy Duncan, Jour. Ind. and Eng. Chem., vol. 3, pp. 177–186, March, 1911.

[2] Mellon Institute of Industrial Research and School of Specific Industries, University of Pittsburgh: Bull. No. 1, Outline of the Smoke Investigation; Bull. No. 2, Bibliography of Smoke and Smoke Prevention, by Ellwood H. McClelland; Bull. No. 3, Psychological Aspects of the Problem of Atmospheric Smoke Pollution, by J. E. Wallace Wallin; Bull. No. 4, The Economic Cost of the Smoke Nuisance to Pittsburgh ,by John J. O'Connor, Jr.; Bull. No. 5, The Meteorological Aspect of the Smoke Problem, by Herbert H. Kimball; Bull. No. 6, Papers on the Effect of Smoke on Building Materials, by Raymond C. Benner; Bull. No. 7, The Effect of the Soot in Smoke on Vegetation, by J. F. Clevenger.

[3] The Electrical Precipitation of Suspended Matter in Gases, by W. W. Strong, Jour. Franklin Inst., vol. 174, pp. 239–263, September, 1912; The Positive and the Negative Corona and Electric Precipitation, by W. W. Strong, Proc. Amer. Inst. Elec. Eng., June 27, 1913, vol. 32, pp. 1305–1314; The Theory of the Removal of Suspended Matter from Gases, by W. W. Strong, Jour. of Industrial and Eng. Chem., vol. 5, pp. 858–860, October, 1913.

[4] U. S. Pats. 1070556, 1071532, and 1096765.
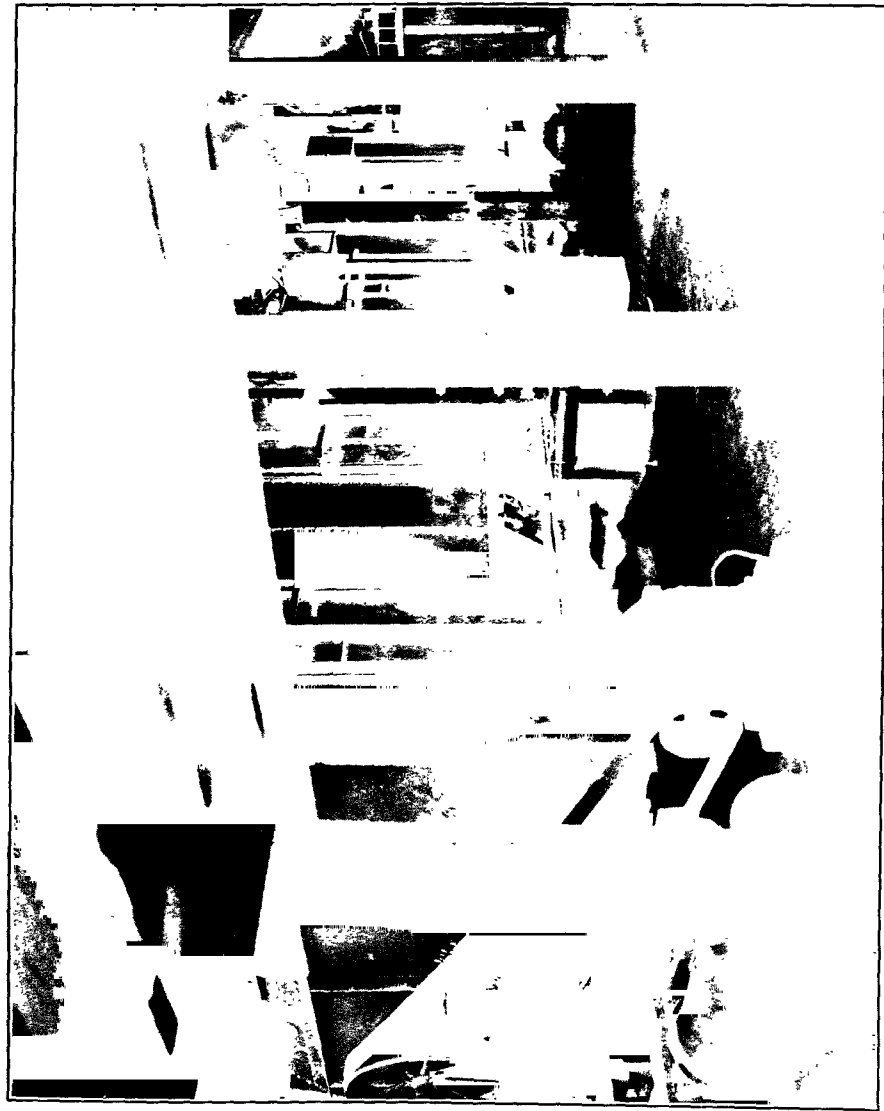
FIG. 41. PRECIPITATOR AT HOOKER ELECTROCHEMICAL CO., SHOWING FAN AND FLUE CONNECTIONS.

PLATE 27

FIG. 43.- PRECIPITATOR AT BUREAU OF MINES BOILER PLANT, PITTSBURGH
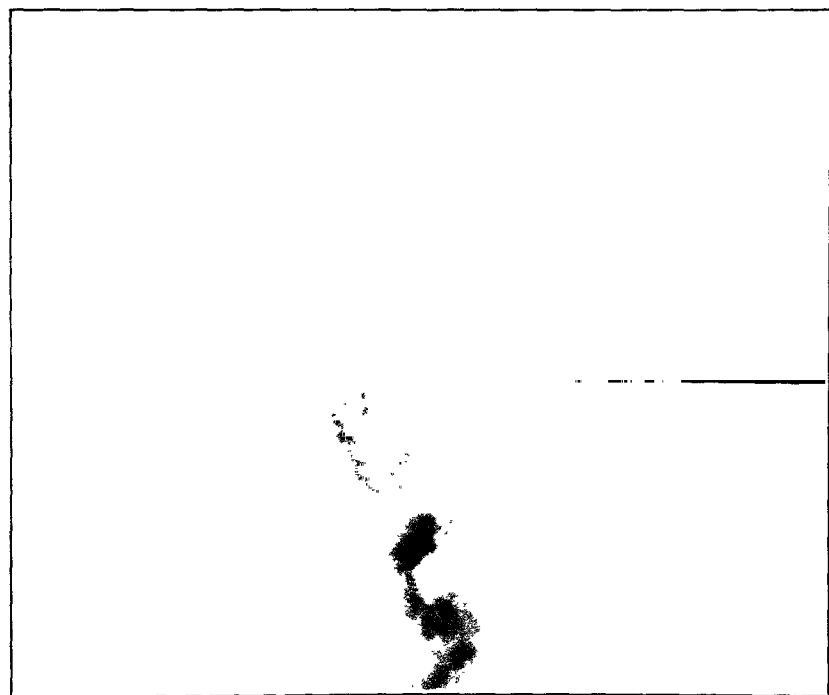
FIG. 42.- PRECIPITATOR IN CITY GAS WORKS.

PLATE 28.

FIG 45.– STACK FROM BOILER PLANT PRECIPITATOR, ELECTRIC
CURRENT ON.

FIG. 44. STACK FROM BOILER PLANT PRECIPITATOR, ELECTRIC
CURRENT OFF

PLATE 29.
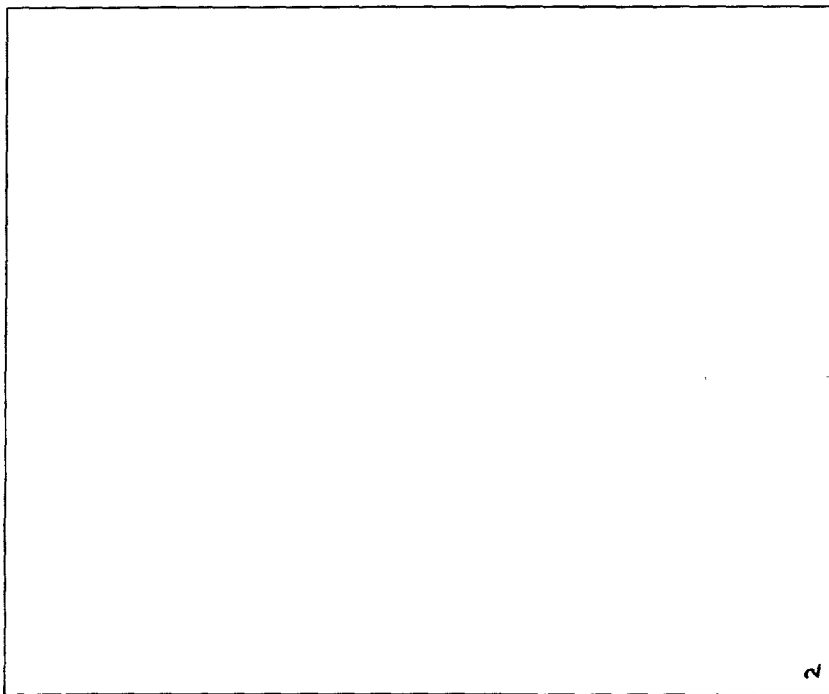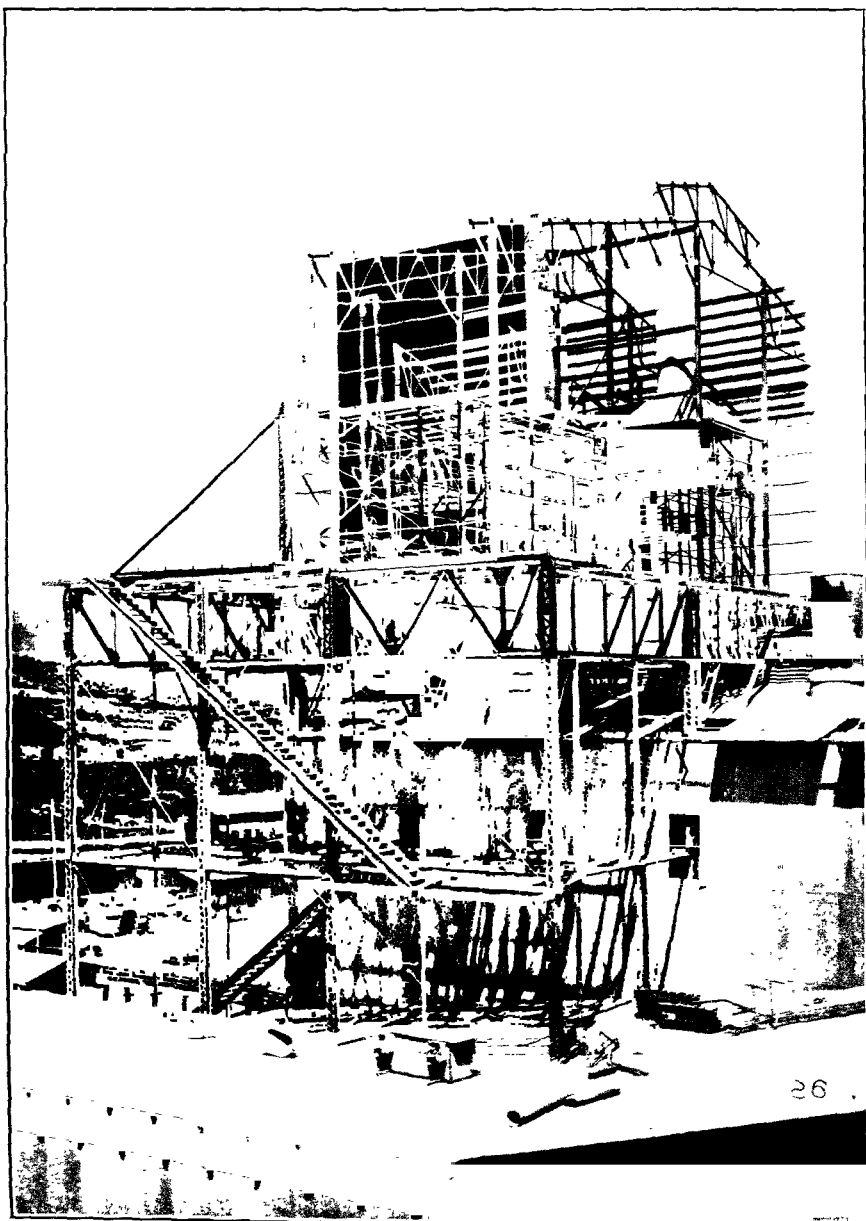
FIG. 46.—CONSTRUCTION OF ELECTRICAL PRECIPITATION PLANT AT RIVERSIDE PORTLAND CEMENT WORKS.

PROBLEMS OF THE PORTLAND-CEMENT INDUSTRY.

The Portland-cement industry is another direction in which the precipitation process has proved of very practical importance. The first installation of this kind was made under the direction of Mr. Walter A. Schmidt at the mill of the Riverside Portland Cement Co. near Riverside, Cal. Threatened litigation with the owners of surrounding orange groves on account of nuisance and damage to fruit and trees from the dust clouds of lime and clay escaping from the cement kilns was the incentive for the cement company undertaking the work. The company had already spent upward of a million dollars in purchases of surrounding land and other expenses connected with the nuisance and damage question, but without securing permanent relief. Experimental work on electrical precipitation was commenced there in the summer of 1911; and as this was almost the first practical extension of the processes to temperatures of 400° to 500° C., many new engineering features had to be worked out. The detai' of the final plant seen in construction in figure 46 and in its present complete form in figure 47 were worked up through the series of preliminary experimental units of progressively increasing size shown in figures 48 to 51. Had there been sufficient ground space available near the base of the kiln stacks the precipitating units might have been placed there and a more compact and far less expensive installation secured; but as it was, the only available space seemed that above the roof at the top of the old stacks. Furthermore, the cement company preferred to incur this additional expense rather than suffer any delay or interruptions of its regular operations while changes were being made in the flues or stacks themselves.

Consequently a reinforced concrete platform 90 by 190 feet was built 80 feet above the ground, strong enough to support the entire electrical equipment upward of 1,200 tons of steel going into the installation as a whole. The present plant consists of 10 rotary kilns, each 8 feet in diameter by 100 feet in length, fired with crude petroleum and furnishing a total volume of nearly a million cubic feet of gas per minute to be treated. Out of this the electrical equipment now collects nearly a hundred tons of dust per day. Figures 52 and 53 show the difference in appearance of the plant before and after making the electrical installation. In figure 49 can also be seen the experimental treater shown in figure 48. Figure 54 shows part of five days' catch of dust sacked and piled.

The treaters are of somewhat the same general type as those used at the Selby and Balaklala smelters, but larger, with wider electrode spacing and many improvements over these in details and general design. There are 20 of them in all, two to each kiln stack connected to it on opposite sides through louvre dampers, such as seen in

figure 55. The grounded electrodes are plates of heavy wire screen reinforced by angle iron ribs, and the discharge electrodes are light iron wires.

Figure 56 shows the operating gallery running the whole length of the row of treaters and containing the motor-generator sets, rectifiers, and transformers, together with their control switchboards, as well as the compressed-air valves governing the operating machinery of the damper and the shaking devices for dislodging the dust from the electrodes. This dust falls into hoppers, from whence it passes by a system of screw conveyors and automatic scales to the storage and car-loading bins. The whole installation requires but one operator, and the electrical-power consumption, including motor-generator and transformer losses, is about 35 kilowatts. The cost of the installation was somewhat less than $200,000. As stated, it was installed purely to overcome the dust nuisance, and was not expected to return any significant values, as the dust is not finished cement, but chiefly raw mix carried out by the gases before it has reached the clinkering zone. The raw mix used contains, however, a small percentage of potash (usually not exceeding 1 per cent K_2O), which largely volatilizes and most of which is condensed and caught in soluble form in the dust, making the latter, even in its crude form, as collected, a fertilizing agent which finds a ready market at nearly as good a price as the finished cement, or by using it over again in the raw mix of a separate kiln a second and higher concentration of the potash may be effected in the dust caught from this.

We thus have another example of a plant, put in at a supposed loss purely to avoid trouble with the neighbors, proving not only to cover its own operating expenses, but to actually pay a rather handsome return on the very considerable investment involved. The plant has been in uninterrupted operation on this basis since January 8, 1913. As this article goes to press the first unit of similar character east of the Mississippi is about to go into service, and in Europe another is under construction.

FURTHER DEVELOPMENT IN PROGRESS.

A number of other installations, each with its features of special interest, might also be referred to, but sufficient has been said to indicate at least in outline the field developing before these processes.

As early as 1907 Mr. Erwin Möller, son of Dr. Karl Möller, already mentioned as one of the pioneers of electrical precipitation, had independently taken up this work in Europe and is now cooperating with the American investigators whose work is described above in the further development of the subject, having also joined with them in the assignment of patent rights to the research corporation for the benefit of the Smithsonian Institution.

PLATE 30.

Sample on Report, etc., omitted
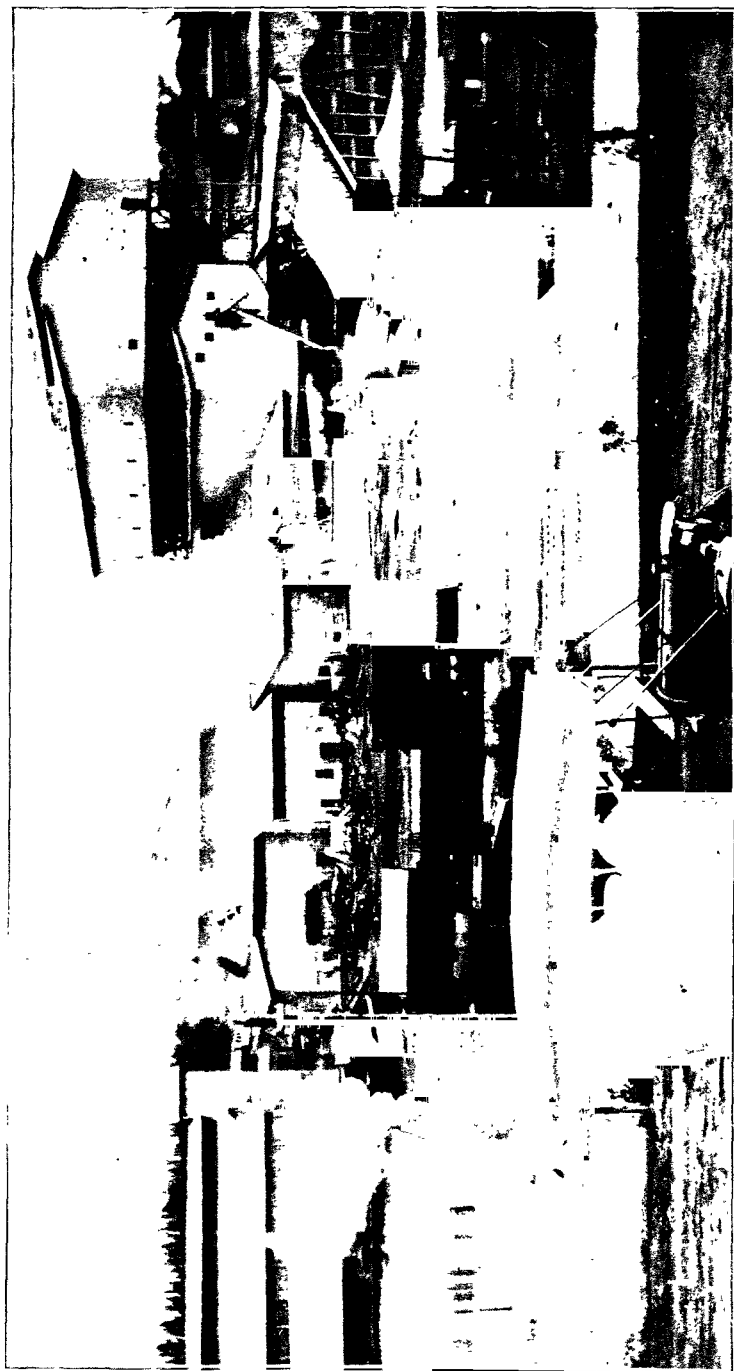
FIG. 47 GENERAL VIEW OF RIVERSIDE PORTLAND CEMENT WORKS, SHOWING ELECTRICAL PRECIPITATION PLANT IN UPPER RIGHT-HAND CORNER.

PLATE 31.

Smithsonian Report, 1913 — Cottrell.

FIG. 48.—EARLY EXPERIMENTAL APPARATUS FOR ELECTRICAL PRECIPITATION AT THE RIVERSIDE PORTLAND CEMENT WORKS.

PLATE 32.
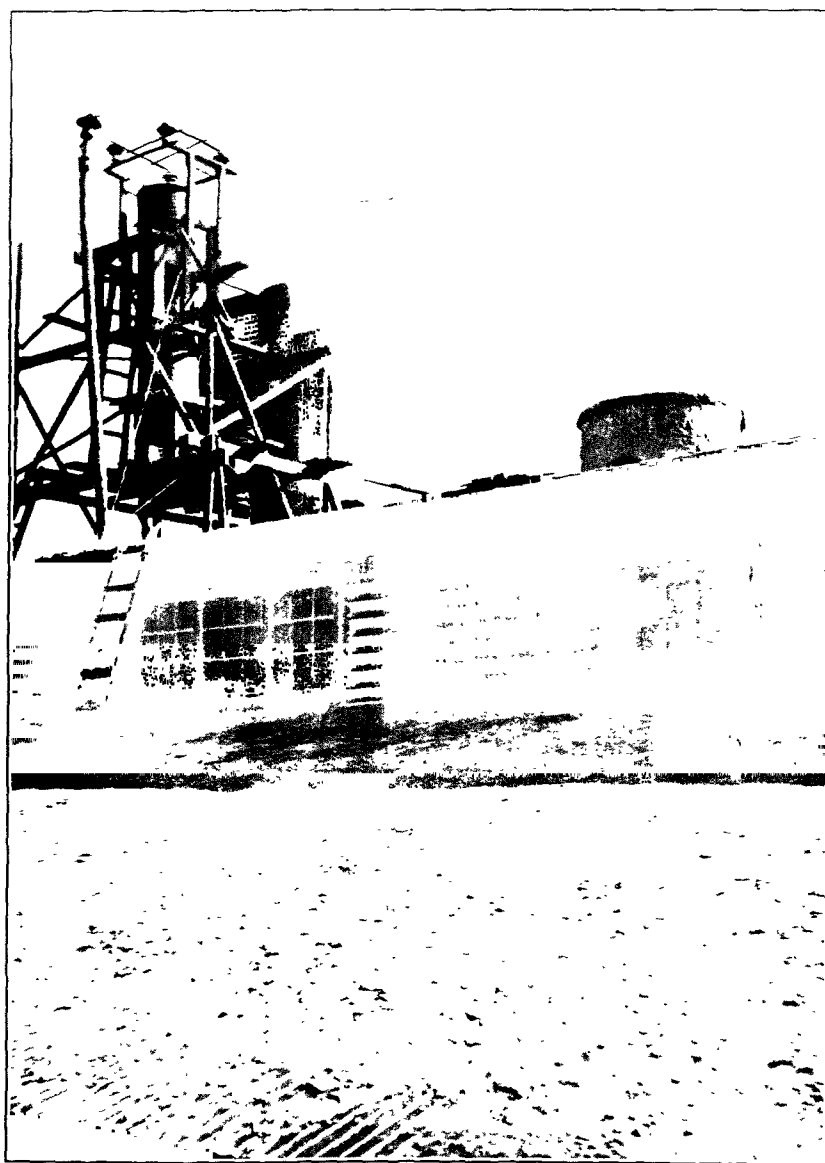
FIG. 49.—EARLY EXPERIMENTAL PRECIPITATOR AT RIVERSIDE PORTLAND CEMENT WORKS.

PLATE 33.

Smithsonian Report 1913.—Cottrell
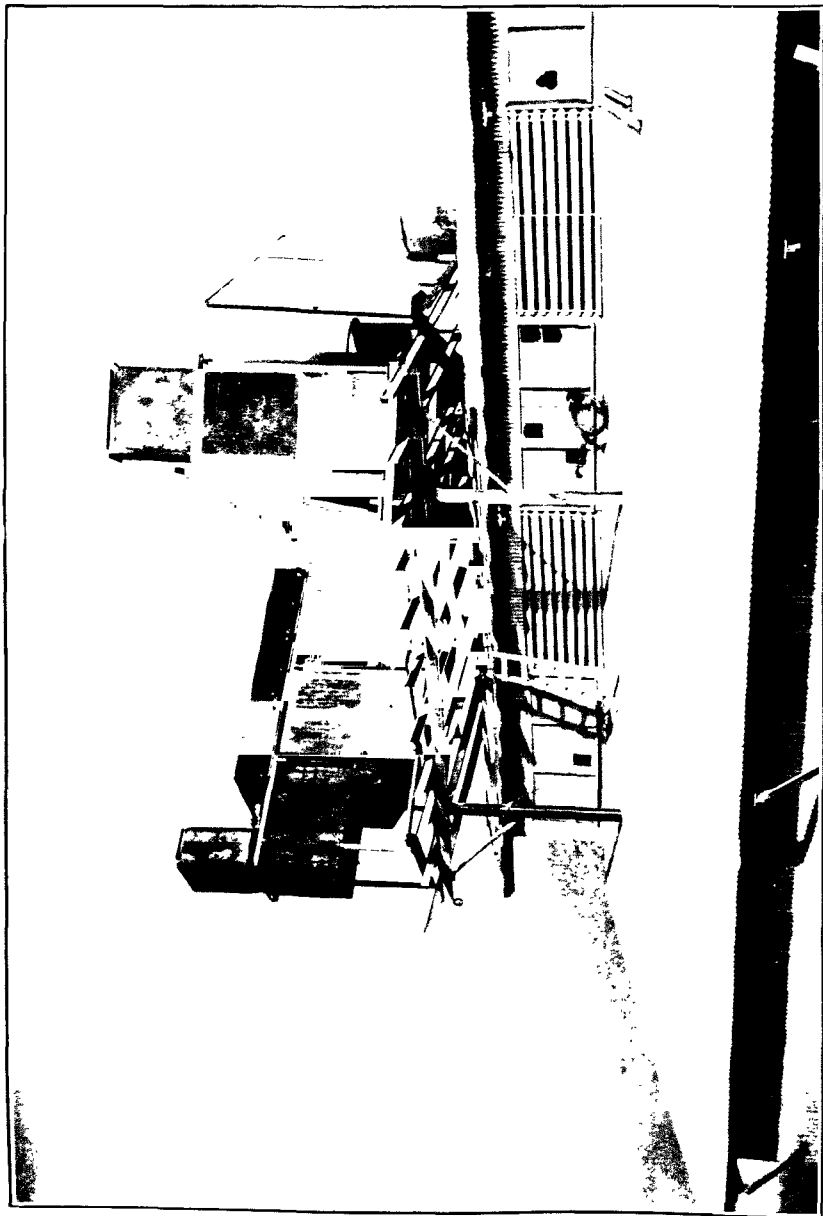
FIG. 50.—TWO EXPERIMENTAL PRECIPITATORS USED FOR COMPARATIVE STUDIES AT RIVERSIDE PORTLAND CEMENT WORKS.

PLATE 34.
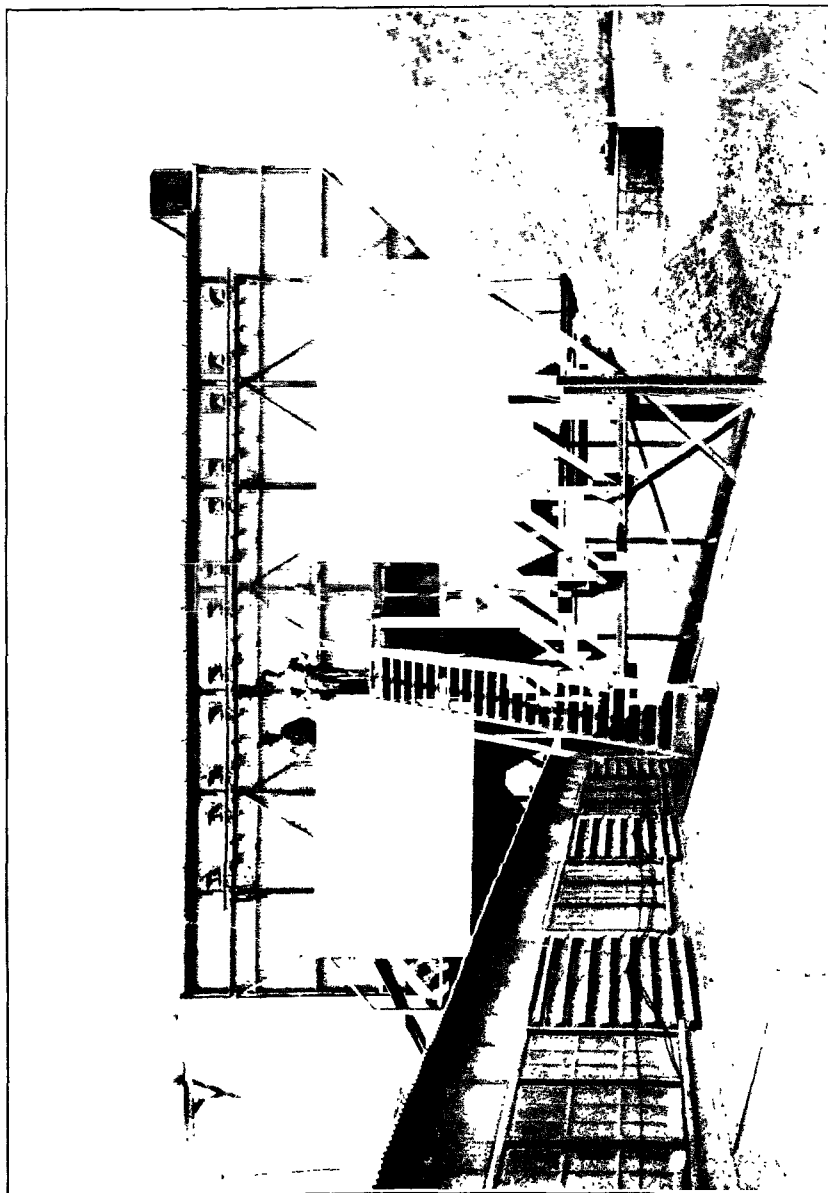
FIG. 51.—FIRST PRECIPITATOR BUILT TO TREAT ALL THE GASES FROM ONE KILN AT RIVERSIDE PORTLAND CEMENT WORKS.
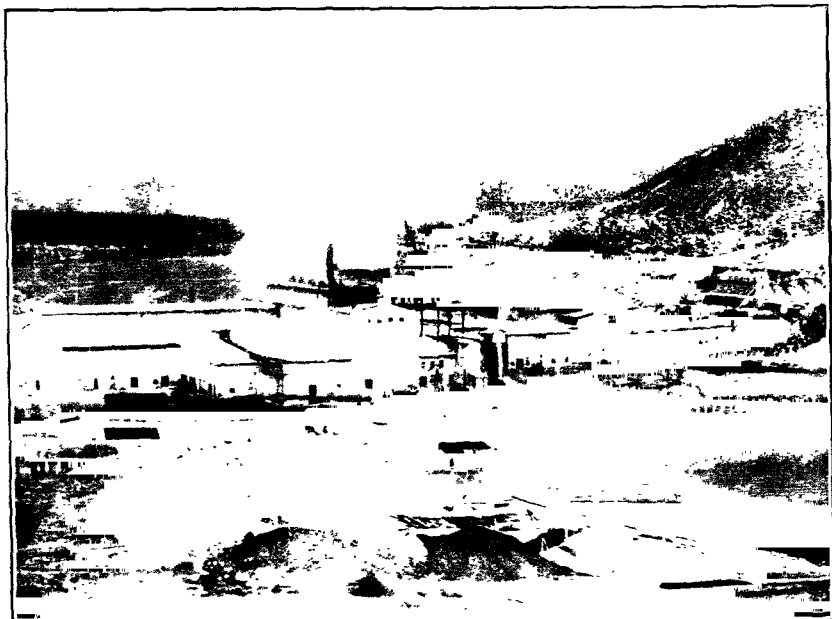
FIG. 52.—RIVERSIDE PORTLAND CEMENT WORKS BEFORE INSTALLATION OF PERMANENT
ELECTRIC PRECIPITATION EQUIPMENT.

FIG. 53.—RIVERSIDE PORTLAND CEMENT WORKS AFTER INSTALLATION OF PERMANENT
ELECTRIC PRECIPITATION EQUIPMENT.

Fig. 54.—Five Days' Collection of Dust by Electrical Precipitation at Riverside Portland Cement Works.

Fig. 55.—Damper of One of the Twenty Electric Precipitation Chambers of the Riverside Portland Cement Works.
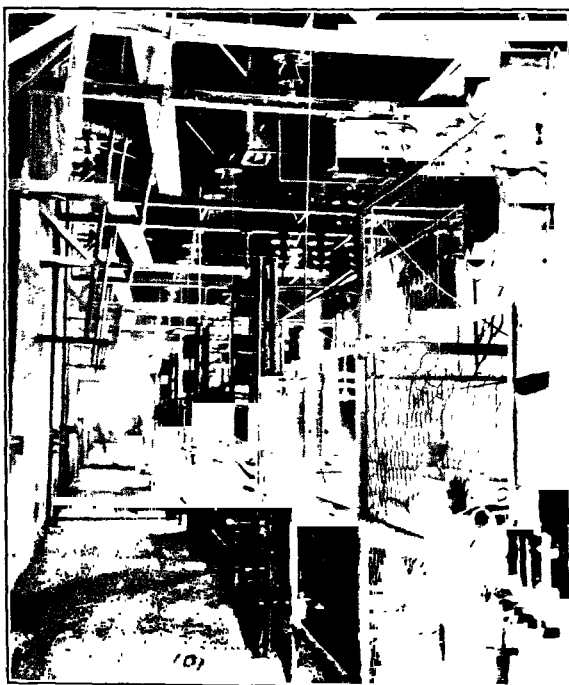
FIG. 56.—OPERATING GALLERY OF ELECTRIC PRECIPITATION PLANT AT RIVERSIDE PORTLAND CEMENT WORKS.
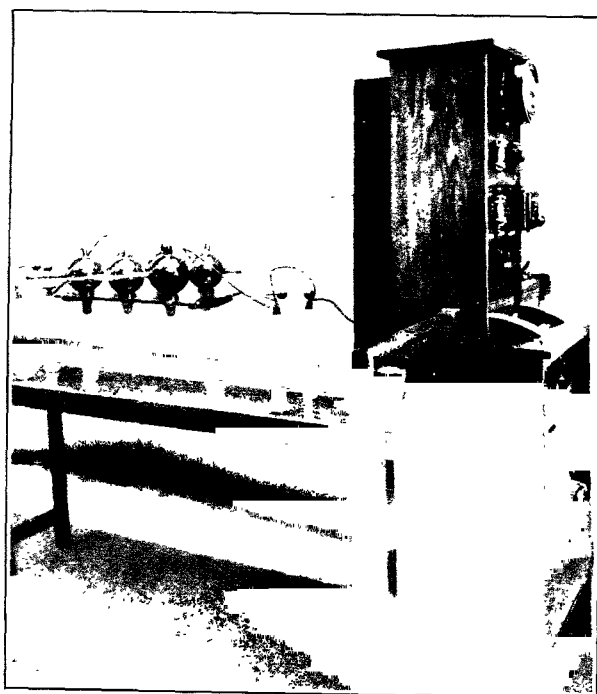
FIG. 57.—LODGE VACUUM VALVES AND CONTROL APPARATUS.

Sir Oliver Lodge and his sons are also once more active in this field and are likewise joining very cordially in the general spirit of cooperation. Their recent technical contributions to the subject [1] have been chiefly in the lines of rectification and insulation. Figure 57 shows some of this high potential current rectifying apparatus, the most novel and essential element of which is a special form of vacuum tube which permits the current to flow through it only in one direction. This may be used either by itself or preferably in conjunction with a mechanical rectifier such as those already described. It appears to have been first devised and used for experiments on the stimulation of growing crops by high potential unidirectional discharges,[2] but its applicability and importance in precipitation work is now being thoroughly investigated, and positive data on this from large-scale tests should soon be available. It is only within the last year that a really active commercial development of the electric precipitation processes has been undertaken in Europe, but at the present time several installations are under construction in various countries, and it is hoped that later a detailed report of this work may also be possible.

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[1] British Patents 25047 and 25047a (1905), also 29268 and 29269 (1912).

[2] John Ernest Newman and Lionel Lodge, Brit. Pat. 17046 (1907).
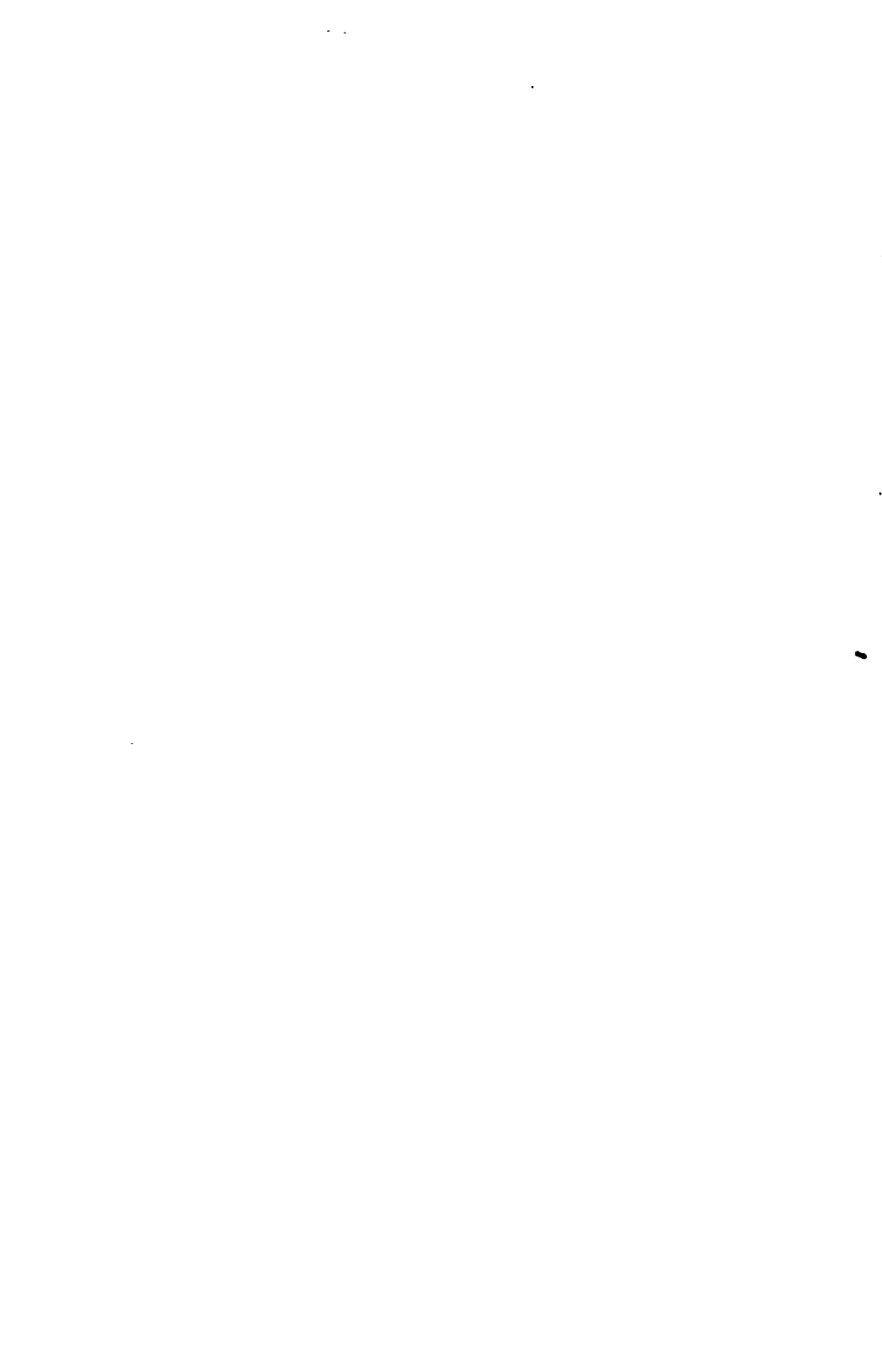
TWENTY YEARS' PROGRESS IN MARINE CONSTRUCTION.[1]

By Alexander Gracie, M. V. O., M. Inst. C. E.

In order to appreciate fully the progress which has been made during the last 20 years in the design and construction of vessels for the mercantile marine, it will be useful to consider briefly the factors for and against advance, so as the better to realize in what direction forward steps have been and may still be possible.

The driving forces toward all progress are healthy discontent with what has been done and the satisfaction derived from greater achievement, quite as much as the hope of material gain. The aim of the shipowner, the naval architect, and the marine engineer is ever toward increased comfort, speed, and economy.

Increase in size is undoubtedly the most valuable resource of the naval architect, as it is directly conducive to the attainment of these three desiderata. The greater the length of a vessel in proportion to her total weight, the smaller becomes the power in relation to her displacement and speed. Greater size gives more deck space for passenger accommodation, greater height above water, and less disturbance due to wave motion; hence, greater comfort. The earning factors, space and displacement, are increased in greater ratio than the cost factors, and thus economy is obtained.

A concrete example illustrative of these principles may possibly be of interest. I will take the case of a cargo vessel having a speed of 13 knots at sea over a 3,000-mile voyage. On a length of 400 feet we can construct a vessel weighing 3,700 tons which would carry 4,000 tons of cargo and consume 500 tons of coal. Each 100 tons of cargo, therefore, involves 92½ tons of constructive material and 12½ tons of coal per voyage. A vessel 500 feet in length would weigh 6,750 tons, would carry 8,700 tons of cargo, and consume 700 tons of coal. Each 100 tons of cargo in this case requires only 77½ tons of vessel and 8 tons of fuel.

The practical success of the large vessel depends, of course, upon the volume of passenger and cargo traffic she can command, and this

varies greatly on the different trade routes. It is notably greatest upon the Atlantic, and in this trade we find the most rapid growth in dimensions.

It is the continued aim of the naval designer to realize the greatest dimensions which the shipowner can utilize on the least possible weights of hull, machinery, and fuel. Every improvement in the quality of materials, every advance in the better distribution of those materials toward the end in view, every reduction in the weight of machinery and of fuel in relation to horsepower, and every progression toward the more effective use of the power developed, is a step toward the ideal large, powerful, and comparatively light vessel.

The introduction of iron about the year 1820, of steel about 1870, of the compound engine in 1854, and of the triple-expansion engine in 1881, were the most notable epoch makers of the first 80 years of steam navigation. The study of the strength problem by means of the " girder " theory and the labors of the classification societies have shown how to combine strength with lightness. The introduction of the experimental tank method of research gave us a definite means of designing form and propellers, so that the least possible amount of power is wasted and the greatest possible amount is usefully applied.

Up to the beginning of the period under consideration the changes which had taken place in marine engineering had been shown in a gradual development of the simple type of reciprocating steam engine. The growing knowledge of the theoretical principles involved in design, the higher standard of materials available for construction, and the steady improvement in machine tools, had enabled engineers successfully to make use of higher steam pressures. The advance marked by the successful introduction of the compound engine about the year 1854 had been followed in 1881 by the introduction of the triple-expansion type of engine, and the three-crank design of the latter proved itself so fit a variation that it has survived, unchanged in all essentials, to the present day. Thus 20 years ago the triple-expansion engine was in the position of rapidly superseding the compound type in almost all services, and was being successfully constructed to work in conjunction with steel cylindrical boilers working at a pressure of 160 pounds per square inch; both engines and boilers being, in general design, not greatly different from those of the same type which are being built at the present time.

I can best convey to you the condition of marine construction at the beginning of the 20-year period immediately under review by recalling some of the most notable achievements of that time.

On the Atlantic the premier vessel was the *Campania*, then regarded as a "monster" ship. It was thought by many that the limit of size had been reached and that so large a vessel could never be made commercially successful. She was 600 feet in length, with a beam of 65 feet and a depth of 41 feet 6 inches. Her gross tonnage was 13,000, her trial speed 22 knots, and her horsepower 30,000. She was, of course, fitted with twin screws, and her engines were of the triple-expansion type, with five cylinders working on three cranks.

The condensers were of cast iron, and, as was usual at that time, formed part of the engine framing. No arrangements were made for balancing the inertia effects of the reciprocating parts. The main boilers were of the double-ended cylindrical type, with a working pressure of 165 pounds per square inch. They burned about 1½ pounds of coal per indicated horsepower-hour and 480 tons daily. Of *Campania's* displacement 48½ per cent was devoted to hull, 21½ per cent to machinery, 14½ per cent to fuel, 4½ per cent to passengers, stores, and water, and 11 per cent to cargo.

The *Campania* carried 570 first-class, 300 second-class, and 600 third-class passengers, and a crew of 400. Her first-class public rooms were six in number; they occupied a total area of 9,214 square feet, or an average of about 16 square feet per passenger, while the average stateroom area was about 17¼ square feet per person. The average number of persons per room was 3.2. Second-class passengers had each but 8 square feet of public room and 14 square feet of stateroom.

Compared with the most modern vessels of large size the *Campania* was shallow, the ratio of length to structural depth being 14.45. In consequence of her somewhat unfavorable proportions as a girder the scantlings of her gunwale and bottom had to be very heavy in order to obtain the necessary longitudinal strength, and it was some years before ships were built in which the upper member of the strength girder was raised to a higher deck. The *Kaiser Wilhelm der Grosse*, built in 1897, surpassed *Campania* in length by 25 feet, but although her sides amidships, as in most subsequent vessels, were plated one deck space higher than in *Campania*, the plating was comparatively light, the deck to which it extended was not plated over, and the top member of her strength girder remained at the upper deck, the length-depth ratio being slightly in excess of that of *Campania*. Her ocean speed was about 22¾ knots, with 30,000 indicated horsepower. Her coal capacity was 4,600 tons. She had accommodation for 600 first-class, 300 second-class, and 800 third-class passengers.

In 1900 came the *Deutschland*, 663 feet in length, similar in appearance and structural arrangements to her immediate predecessor, her

length-depth ratio being over 15, and the main girder stopping at the upper deck level, 44 feet above the keel. Her horsepower was in the neighborhood of 35,000 and her ocean speed was about 23¼ knots; capacity for 4,800 tons of coal was provided. The engines were of the greatest actual dimensions reached in the reciprocating type, and were of the four-crank quadruple design. The *Deutschland* accommodated 700 first-class passengers in 266 rooms, an average of about 2.6 persons per room; 300 second-class, and 290 third-class passengers. Luxuries were beginning to creep in, some of the state-rooms having a private bathroom attached, while for the suites as much as £250 was charged for a single voyage.

In 1901 length was increased by 20 feet in the *Celtic*, built for the White Star Line: she was 680 feet in length, with a beam of 75 feet and a depth of girder of about 52 feet. In this. as in most vessels of the White Star fleet, only a comparatively low speed was provided. The consequent smallness of horsepower reduced both first cost and fuel consumption, while the fuller form gave roomier deck spaces and greater dead-weight carrying capacity. Since the total dead-weight was augmented and the proportion given up to coal reduced there was a twofold increase in the weight of freight-earning cargo. Speed is an expensive item. On the length of 680 feet a 16-knot vessel can carry 12,000 tons of cargo on an expenditure of 2,000 tons of coal over an Atlantic voyage, while an advance in speed to 22 knots would reduce cargo to 3,000 tons and involve a coal consumption of 3,500 tons. besides increasing first cost by about 25 per cent.

Next year came *Kaiser Wilhelm II*, 684 feet long and 44¼ feet in depth to her upper deck, but with her sides plated all fore and aft up to the level of a continuous promenade deck 8¼ feet above the upper deck. Her depth of girder was thus 52½ feet, and her length-depth ratio only 13. A better distribution of structural material was realized, and excessively heavy local scantlings were avoided. Besides having her main structural weights higher than usual, she had one deck more above her main structure than any of her predecessors, and these additions to the weight and height of her upper structure necessitated a corresponding increase in breadth, which was made 72 feet, as compared with *Campania's* 65 feet and *Deutschland's* 67 feet. Similar increments in transverse dimensions in relation to length have characterized all subsequent advances, and the number of super-structures has steadily increased in order to afford deck space for the greater number of public rooms and more spacious cabin accommodation by which each successive vessel was rendered more and yet more attractive. *Kaiser Wilhelm II* had four engine rooms, in which were developed about 45,000 indicated horsepower, and a speed of over 23½ knots was maintained at sea. Her coal capacity was 5,000 tons. Accommodation was provided for 770 first-class, 350 second-

class, and 780 third-class passengers. Four hundred pounds was charged for a suite of rooms.

The power transmitted per shaft in this vessel was about 25 per cent greater than in the previous unit, and two three-crank quadruple engines were fitted to each line of shafting in order to reduce the dimensions of the cylinders and working parts, a scheme which lent itself naturally to more complete subdivision into watertight compartments. This arrangement, which was also tried in some naval vessels, was, however, not repeated in later practice. The machinery of this ship exerts the largest power of any installation of reciprocating engines in the merchant service, the next advance in total effort being with turbine machinery.

Within the next few years there appeared the *Cedric*, *Amerika*, and *Kaiserin Augusta Victoria*, all about 680 feet in length, and carrying still further the development in number and extent of superstructures, public rooms, and luxurious cabin accommodation. The *Amerika* had six decks above the water line, as compared with *Campania's* four. In none of these vessels was high speed attempted.

The further development of the reciprocating engine since the beginning of the period under survey has been in the use of still higher initial pressure and in the extension of the range of useful pressure in the quadruple-expansion type of engine. The use of higher pressure followed naturally upon the success of the triple engine, and for pressures above 180 pounds per square inch the quadruple type became necessary in order to take the fullest advantage of the increased heat energy available in the steam.

Compared with the gain in fuel economy effected by the triple-expansion over the compound engine, the further improvement due to the increase in steam pressure to 215 or 220 pounds is naturally small, being about 7 to 8 per cent, and against this has to be put the increased weight, cost, and upkeep of the quadruple type. For ships trading on long voyages, and more especially for passenger ships, or large units, where a four-crank engine would be fitted in any case, on account of its greater smoothness in running, the quadruple engine has now superseded the triple-expansion type; but in the case of cargo carriers, where low first cost and easy supervision are primary conditions, the triple engine still holds its own.

In the essential design of the reciprocating main engine, improvements seem difficult to attain. Some changes, however, may be noted. Condensers are now usually kept separate from the main framing, and, in order better to withstand extremes of temperature, are frequently constructed of mild steel, instead of being cast as formerly; much more attention is also given to their design, with a view to improve thermal results. Air pumps have been improved in design, and in most large or fast-running machinery are now

fitted as separate auxiliary engines, instead of being driven from the crossheads. Attention has been directed to devising means of balancing the engines in order to reduce vibration troubles. The first attempt to solve the problem of balancing was made by Messrs. Yarrow, and the method known as the Yarrow-Schlick-Tweedy system is now adopted in most engines of the four-crank type. This method consists in arranging the relative positions of the various reciprocating and revolving masses by adjusting the angles between the cranks so that the inertia effects are reduced to a minimum. Reduction in fuel consumption has been obtained by the collective effect of a number of small savings; by the improved condenser and air pump; by the utilization of the auxiliary exhaust for feed heating; and by heat economy in various ways.

In the constant endeavor to provide greater intensity in power production, increase in piston speed and rate of revolution has been achieved through experience in design and a better quality of material and workmanship; but where conditions of exceptional power, or lightness per unit of power, or both of these, have to be considered, the limitations of the reciprocating type of engine become apparent. In addition to the difficulties of construction and management of very large units, the reciprocating engine had, as already remarked, reached a point where further improvement in steam consumption was not easily attained, while further reduction in weight involved increase in speed of rotation, with its attendant difficulties. Thus the introduction of the steam turbine proved opportune, by providing a way to further progress in economy, lightness, and the construction of very large units, while at the same time eliminating vibration troubles and relieving difficulties of engine-room management.

The turbine entered the Atlantic lists in 1905, when the *Victorian* and *Virginian*, 520 feet in length, took up their stations, and in 1905 the 650-foot *Carmania* also used the new motor.

The 700-foot mark was passed in 1906 by the building of the White Star liner *Adriatic*, 709 feet by 75 feet by 56 feet, with twin-screw quadruple-expansion engines of about 15,000 indicated horsepower.

Her speed was but 15 knots, and she carried 450 first-class, 500 second-class and 1,400 third-class passengers, 2,500 tons of coal, and 6,500 tons of cargo. Of her total displacement, hull claimed about 56 per cent; machinery, 10 per cent; fuel, 8 per cent; cargo, 21 per cent; passengers, stores, and water, about 5 per cent. A comparison of these approximate figures with those already given for the *Campania* shows that, per annum, the *Adriatic* could carry twice as many passengers and three and a half times as much cargo per ton of fuel as the *Campania*. This well illustrates the cost of speed, and justifies the enhanced rates charged to those availing themselves of the faster vessels.

The turbine, having proved its worth in the realm of high power and fast steaming, was boldly adopted by the Cunard Co. in the *Lusitania* and *Mauretania*, built in 1907. These vessels surpassed all others, with a length of 760 feet, 88 feet of beam, and 60½ feet depth of girder. The girder ratio was thus about 12½, and for the first time high-tensile steel was utilized in the upper member to meet the higher stresses. Some lightening of structure was thus obtained. These ships were the first mercantile vessels to have four lines of shafting, and practically the whole of the vessel's length was occupied by boilers, machinery, and fuel. About 68,000 horsepower was developed, and an ocean speed of between 25 and 26 knots regularly maintained on an expenditure of about 5,000 tons of coal per voyage. Although already surpassed in dimensions, these two vessels retain their supremacy in speed unchallenged.

In 1908 a further step was taken with a view to securing a greater reduction in steam consumption per effective horsepower. This consisted in the combined use of the reciprocating steam engine and turbine in order to retain the low speed of revolution of the reciprocating engine, with its accompanying favorable propeller efficiency, while at the same time effectively utilizing the expansion of the steam to the condenser pressure. The first ship to be thus fitted was the *Otaki*, a vessel of 464 feet in length and about 9,900 tons dead weight capacity; and a comparison of this ship with a sister ship fitted with ordinary twin-screw quadruple-expansion engines showed a difference of about 20 per cent in steam consumption per effective horsepower in favor of the combination type of machinery.

The system is principally suited to vessels of fairly large power, moderate speed, and for service on long voyages. The usual practice has been to fit the reciprocating engines on the wing shafts, and the exhaust turbine on a center shaft, an arrangement being made for exhausting the steam from the reciprocating engine direct to the condenser, and thus cutting out the turbine during maneuvering. Combination machinery, as compared with all reciprocating machinery, involves more complexity and cost, and a slight increase of weight in the engine room; but the improved economy realizable allows of reductions in the boiler capacity and in boiler room and fuel weights, which more or less compensate for this. The influence of the last item is dependent on the length of voyage.

In 1911 a length of 850 feet was reached in the White Star liner *Olympic*. This luxurious vessel measures 852 feet by 92 feet by 64 feet, and has a speed of 21 knots with 46,000 horsepower combination machinery driving three screws. She carries 735 first-class, 674 second-class, and 1,026 third-class passengers, and has the following public rooms: Gymnasium, reading and writing room, lounge, smoke room, veranda and palm court, restaurant, reception room, dining saloon,

racquet court, swimming bath, and Turkish baths. Each of her finest suites consists of sitting room, two bedrooms, bathroom, and clothes rooms, and occupies 800 square feet or 160 square feet per person accommodated.

To-day the largest vessel afloat is the *Imperator*, 880 feet by 90 feet by 63 feet. Her girder ratio is 10.7, and she has eight decks above her water line. With boilers of the Yarrow type and turbines of 62,000 horsepower driving four shafts, she has an ocean speed of 22½ knots. She carries 900 first-class, 800 second-class and 2,700 third-class passengers, with a crew of 1,200, or 5,400 persons in all. Her accommodation is the latest word in spaciousness and luxury. For first-class passengers there are two large and three smaller dining saloons, restaurant, grillroom, ladies' room, ballroom, winter garden, smoke room, gymnasium, swimming bath, and Turkish baths, the total area given up to public rooms being 36,000 square feet, or about 40 square feet per passenger. She has 446 first-class staterooms, including 12 suites, the average number of persons per room being thus practically two, and the average room area 80 square feet per person.

In the all-turbine installation for the merchant service the turbines have been mostly of the compound type—that is, with the steam passing through two turbines in series—the usual arrangement being a three-shaft one, having one high-pressure turbine and two low-pressure turbines, with the exhaust from the high-pressure turbine passing through the two low-pressure turbines in parallel. Only in some few cases has a twin-screw arrangement been adopted—that is, with the high-pressure turbine on one shaft and the low-pressure turbine on the other—but a similar arrangement, duplicated, has been applied to many of the largest installations, both naval and merchant, by fitting two independent sets, of two turbines each, working on four lines of shafting. With a view to improving the steam economy in the all-turbine system, a further development has been introduced in some recent ships of large power having a four-shaft arrangement, by passing the steam through three turbines in series. The steam passes through the high-pressure turbine to the intermediate-pressure turbine, and then through the two low-pressure turbines in parallel, there being one turbine on each line of shaft. The result of this is that for the same overall length of each turbine unit (a matter of some practical moment) the steam passes through a greater number of rows of blades and a condition of improved efficiency is gained, while a reduction of the blade leakage is obtained, due to the relatively greater length of blade as compared with the alternative two-series design. The improved turbine-efficiency resulting from this arrangement thus increases the range of speed at which an all-turbine set can successfully compete with the reciprocating engine. Several ships with turbine machinery of this three-series type have lately

been put on service, with very satisfactory results even at comparatively low speeds.

The rapid development of the large, luxurious and fast liner which I have just traced has been due to the exceptionally favorable conditions of the Atlantic route. Here there is a large and steady stream of passenger traffic, a demand for expensive and luxurious accommodation, and a comparatively short distance between terminals. Fuel of the best quality can be readily obtained on both shores. Upon the other great ocean highways of the world these advantages do not exist. The Pacific lane from Vancouver to Nagasaki is 67 per cent longer than that from Liverpool to New York, Vancouver to Melbourne 148 per cent longer, London to Melbourne 315 per cent, and Southampton to Cape Town 95 per cent. Neither Japanese, British Columbian, Australian, nor South African coal is equal to Welsh coal in calorific value, but on the Pacific oil fuel is easily obtained, and is already beginning to be largely used. In no case does the volume of passenger traffic approach that across the Atlantic. As a consequence competition is less keen, there are fewer vessels, a less number of voyages per vessel, and the vessels themselves are smaller and of less speed. Nevertheless considerable progress has been made in size, accommodation, comfort, speed, and economy, although the advance in speed has not been so marked as that between Britain and America.

No less interesting than vessels of the liner class are those smaller passenger carriers known as cross-channel steamers. Between different ports in the United Kingdom and between British and continental ports there has always been a large passenger traffic and the competition between the various railway and other companies has developed a large fleet of small vessels, whose speeds vie with those of Atlantic liners and whose speed-length ratios, or ratios of speed to square root of length, are generally in excess of liner practice.

The conditions of these cross-channel services differ materially from those of the liners' routes. The distances are much shorter, ranging from 21 to 120 miles only, and the number of times the vessels enter harbor is much greater.

The quantity of fuel which must be carried is therefore much less, and economy of consumption is relatively of smaller influence. It is of greater importance to keep down tonnage, to save dues, and to reduce weight wherever possible in order to obtain high speeds upon small dimensions. Very few of the vessels are classed, and the scantlings in all cases are kept as low as possible. In many cases harbor accommodation imposes severe restrictions upon length and draft.

Twenty years ago the majority of these vessels were paddle steamers. These were gradually replaced by twin-screw steamers, and

these again were superseded by turbine-propelled craft, which to-day are practically universal in the channel services.

Typical vessels in 1893 were the paddle steamer *Calais Douvres* and the twin-screw *Ibex*.

The *Calais Douvres* was 324 feet in length, 36 feet in breadth, and 14 feet deep; of 1,065 gross tons and 6,000 indicated horsepower, she had a speed of 20.64 knots and a speed-length ratio of 1.15.

She was unclassed, her hull weighing 805 tons and her machinery 650 tons—9¼ indicated horsepower per ton—and she carried 103 tons of coal. Her displacement was made up as follows:

	Per cent.
Hull	48
Machinery	39
Coal	6
Passengers, stores, and water	7
	100

Her accommodation consisted of 10 deck staterooms, furnished with sofas only, and large, open saloons below deck. She carried 580 first-class and 300 second-class day passengers.

The *Ibex*, of 1,062 gross tons, measured 265 feet by 32½ feet by 15½ feet, and with 4,200 indicated horsepower realized a speed of 19.37 knots, the speed-length ratio being 1.19. Her machinery developed 10¼ indicated horsepower per ton and her weights were thus distributed:

	Per cent.
Hull	60
Machinery	30
Coal	4½
Passengers, stores, and water	5½
	100

Her accommodation consisted of two private cabins and a number of open saloons with sleeping accommodation on sofa berths. She carried 292 first-class and 265 second-class day passengers.

Other notable vessels of this period were:

Name.	Machinery.	Length.	Tonnage.	Speed.	Speed-length ratio.
Princesse Henriette	Paddle	300	1,100	20.50	1.18
Leopold II	do	340	1,367	22.00	1.19
Princess May	"	280	1,123	20.00	1.19
Tudie	...	269	802	21 35	1.30
Frederica	do	265	1,059	19.50	1.20

During the succeeding 10 years many other similar vessels were put into service, their lengths ranging from about 270 up to 300 feet and their speeds from 19 to 24 knots. The most remarkable of these were perhaps the four screw steamers *Connaught, Leinster, Munster,*

and *Ulster*, which, on a length of 360 feet, attained a speed of 24¼ knots, a speed-length ratio of 1.28, and the *Empress Queen*, still the largest paddle vessel in this country, 360 feet in length and of 21¼ knots speed.

In 1903, encouraged by the success of the turbine steamers *King Edward* and *Queen Alexandra*, built, respectively, in 1901 and 1902 for service on the Firth of Clyde, the first turbine channel steamer, *The Queen*, was placed on the Dover-Calais route. This notable vessel, 310 feet by 40 feet by 25 feet, of 1,676 gross tons, has turbine machinery of about 8,500 horsepower, and attained a speed of 21.8 knots, equal to 1.24 times the square root of her length. In the same year the turbine steamer *Brighton*, 274 feet in length, steamed 21.37 knots, giving a speed-length ratio of 1.29. The success of these two vessels led to a rapid development of turbine propulsion, and the almost total abandonment of reciprocating machinery in the channel services. In 1905 the *Princess Elizabeth*, with turbines and water-tube boilers, made 24 knots on 357 feet, and the *Dieppe*, with turbines and cylindrical boilers and classed at Lloyd's, brought the speed-length ratio up to 1.31, with 21.65 knots and a length of 274 feet.

To attain high speeds in relation to length, saving of weight is of vital importance, and the advantages of water-tube boilers in this respect are considerable. All that prevented their more general adoption was their lack of robustness and the greater care and skill required in handling them, as compared with the well-tried and well-known Scotch type of steam raiser. By their use in the turbine steamer *Newhaven*, built in 1910 as successor to the *Dieppe*, a trial speed of 23.85 knots was obtained on a length of 292 feet, the speed-length ratio being raised to 1.4. This result was made possible by the extreme lightness of the machinery installation in relation to the power developed, 13,000 horsepower being obtained from a weight of only 590 tons. Thus 22 shaft horsepower was developed per ton, about two and a half times that obtained from paddle machinery and double the output of twin-screw reciprocating engines. The displacement of the *Newhaven* was 1,510 tons, only 200 tons in excess of that of the *Dieppe*, although the later vessel was 18 feet longer and twice as powerful.

The outstanding difficulty in applying the steam turbine to marine propulsion has always been that while high speed of rotation is necessary to obtain the maximum turbine efficiency, the propellers are most efficient at very much lower speeds. Electric, hydraulic, and gear-wheel transmission have each been used to combine a high-speed turbine with a slow-running propeller in order to obtain the maximum efficiency of each.

Where a suitable gear ratio can be adopted, not only can improved propeller efficiency and decreased consumption of steam per unit of

power developed be obtained, but it is possible, by overspeeding the turbines at full power, to maintain the economy over a larger range of the ship's speed than could be done with a direct-coupled turbine. With the gear-wheel method of speed reduction a considerable amount of experience has now been obtained, and up to the present time two small cargo vessels and seven cross-channel steamers have been put on service, while four sets each of about 12,000 horsepower are under construction, two for ocean liners and two for swift coasters.

In 1911 the channel steamers *Normannia* and *Hantonia* were each fitted with four turbines. two running at 2,000 and two at 1,400 revolutions, and connected by means of toothed-wheel gearing to two propeller shafts running at 310 revolutions per minute. The experiment was a notable success, the coal consumed per trip being only 43 tons as compared with the 70 tons used by the immediately preceding vessels, which were of the same capacity but propelled by direct-driven three-screw turbines.

Last summer the channel steamer *Paris*, $293\frac{1}{2}$ feet in length and having geared turbine propulsion, attained the remarkable speed of 25.07 knots on a run from Newhaven to Dieppe, the speed-length ratio working out at 1.47—a result which has only been surpassed by torpedo craft.

The introduction of toothed gearing for the main drive has been looked upon by many as a retrograde step. The conditions are, however, in no way similar to those in which formerly gearing up was necessary, and where a very variable turning moment in the reciprocating engine had to be contended with. The loss in transmission is small, being probably not more than 2 per cent of the power transmitted, and the wear on the teeth is inappreciable. Some objection has been raised to the noise caused by the gearing, but, although doubtless not so silent as the direct-driven turbine, the geared-turbine installation can compare favorably with the reciprocating engine in this respect. The actual vibration transmitted through the structure of the ship is inappreciable; the effect of the gearing being felt altogether in an air vibration in the engine room itself, and this will be reduced to a minimum with the more accurate methods of gear cutting recently introduced.

The large speed reduction which can be effected makes the system suitable for ships of low speed and moderate power, and it is almost certain that this method will greatly extend the usefulness of the steam turbine for marine propulsion.

In Germany the hydraulic transmitter invented by Dr. Fottinger has lately been developed. The principle of the transmitter is that of combining a high-speed turbo-centrifugal pump with a water turbine designed for a lower speed of revolution. The former

is coupled direct to the steam turbine and the latter to the propeller shaft, the pump and water turbine being placed in one casing and so designed that the frictional and eddy losses are reduced as far as possible. Some small installations have been fitted for marine purposes, a transmitter has been tested with a load of 10,000 shaft horsepower, and it is proposed to fit several large German vessels with the system. A transmission efficiency of about 90 per cent is claimed at full load, with a slight reduction at light loads. The ratio of primary to secondary speed is normally about 5:1, but transmitters could be designed for larger ratios.

Electrical transmission has now been applied to several vessels. Alternative schemes have been tried in which the power is generated by steam turbo-generators, and by generators driven by Diesel oil engines, and applied to the propeller by alternating-current motors. Considering the transmission efficiencies likely to be attained and the increased weight and initial cost of the installation, it does not appear probable that a system of this kind will be able to compete successfully, in ordinary cases, with the direct-driving engine or mechanically geared turbine. Where, however, power has to be provided for other than propelling purposes (in which case the same generating plant could be available), it is possible that this system would have advantages.

Within the period under review, vessels built solely for the purpose of carrying cargo have undergone notable development. The principal object of the owner of such vessels is to secure improved economy in each successive addition to his fleet, speed and accommodation being secondary considerations. And here again I have the same story to tell—the story of increase in dimensions and of reduction in fuel consumption in relation to work done.

The following table shows the steady advance in the vessels of one well-known line of cargo tramps:

	Tons, dead-weight.
1895	6, 400
1899	7, 200
1905	8, 200
1912	9, 300
1913	9, 600

The speed has remained practically constant at 11 knots, but while the 6,400-ton dead-weight carrier of 1895 developed 1,400 indicated horsepower and consumed 24 tons of coal daily, her successor of to-day can carry 9,600 tons and steam at the same speed on an expenditure of only 32 tons daily for 2,300 indicated horsepower. Fifty per cent more dead weight is carried and 64 per cent more power developed, but only 33 per cent has been added to the coal account.

The coal rate has fallen from 1.6 pounds per horsepower per hour to 1.3 pounds, while for a 3,000-mile voyage the dead weight carried per ton of coal has increased from 23.5 tons to 26.4 tons.

Rapid loading and discharge of cargo are of vital importance to the tramp vessel, and it is evident that the less the cargo has to be moved horizontally along holds and 'tween decks before coming under the hatchways to be lifted, the more rapidly can it be handled. Hatches have therefore increased greatly in size, and in some vessels are now almost continuous, and in breadth nearly equal to half the vessel's beam. With the same object of facilitating the passage of cargo to and from the hatchways, hold pillars have almost disappeared, and in place of the double row of slender pillars at intervals of about 4 feet, we find large open holds and decks supported by continuous longitudinal girders under the beams and four large plate-and-angle pillars only.

The steam winch still remains the best means of handling cargo, being more robust and less complicated than either electric or hydraulic plants. The winches themselves have been greatly improved, and instead of a single 6-inch by 10-inch winch at each hatch and chain falls we find a pair of 8-inch by 12-inch machines with helical gearing and wire-rope pendants. The normal derrick is now of steel tube for a 6-ton lift in place of the old 3-ton wood derrick, while a special steel derrick at each end of the vessel can handle a load of 30 tons. At the same time the size of the drums has increased from 12 inches to 24 inches and the working pressure from 50 to 100 pounds. Larger wearing surfaces have been provided and locomotive-type valves fitted, so that the cargo winch of to-day is not only more powerful and more rapid than its predecessor, but has also greater immunity from breakdown.

Crews' accommodation has been greatly improved. Comfortable mess rooms are now provided separately from sleeping quarters; galvanized-iron berths have replaced wooden bunks; steam heating and stoves are provided; each man has a locker fitted with drawers for his clothes, and his chest goes to a separate storeroom; there are plunge and shower baths for seamen and for firemen as well as for the captain, officers, and engineers, and a well-equipped hospital is provided.

The triple-expansion engine still holds its place in the engine room of the cargo tramp. The fourth cylinder of a quadruple engine would mean additional complication and one or two additional engineers. Three main boilers of equal size are used, two under forced draft for propulsive purposes, the third under natural draft for dealing with cargo and to assist the others in cases of emergency when a little extra speed is called for.

In comparison with the 1,000 tons of coal consumed daily by the swift liner, the 30 tons of the cargo tramp appears so small that it would seem hardly worth while to attempt to reduce it; but the one-half pound of oil per brake horsepower-hour of the Diesel engine, together with the saving in weight and space and in time for bunkering, is already attracting the attention of the owners of cargo vessels, and the economy of the geared turbine proposition is also being considered.

In numbers and dimensions there has been a rapid development of vessels built for the carriage of petroleum in bulk. In 1893 Lloyd's Register contained the names of 47 vessels engaged in carrying oil cargoes, and 17 were in course of construction. The largest on service was the *Turbo*, 350 feet in length, and capable of carrying 5,000 tons of oil in bulk. To-day there are 370 oil vessels on the register, the largest being the *San Fraterno*, 530 feet in length, and loading 15,700 tons of oil.

Vessels specially fitted with refrigerated holds for the carriage of perishable cargoes, such as fruit and meat, have also been greatly developed and improved.

The steam yacht has passed through structural changes not dissimilar to those which have affected mercantile vessels. Dimensions have generally increased and superstructures have been added. The weather deck is now higher above water, and the principal accommodation and public rooms are carried out to the ship's side in place of being confined to a long deckhouse. Turbine propulsion has in many cases been adopted with success in place of reciprocating engines.

I regret that within the limits of the time at my disposal this evening I can not refer in detail to many other notable changes which have taken place during the past 20 years, such as the disappearance of the sailing ship, the wide application of engine power to fishing boats, barges, and other small craft, and the remarkable performances of the hydroplane boat. These would of themselves take up an entire evening.

With regard to the changes in boiler design and construction, these have been small. The cylindrical boiler has remained almost unchanged in general design during the last 20 years. Boiler shell plating, owing to the higher pressures now adopted, is much heavier, and where weight is a consideration is often of high-tensile steel. Boilers of the water-tube type, which have entirely superseded those of the cylindrical type in warships, have made but little progress in the favor of the average shipowner, and have been adopted only to a very limited extent in merchant ships in this country. Recently, however, their great advantages in lightness have secured their adop-

tion in several channel steamers, and some small Australian vessels have been fitted with boilers of the Babcock-Wilcox type. A considerable departure has been made in the fitting of the large German Atlantic vessel *Imperator* with boilers of the Yarrow type; and in a large liner at present under construction on the Clyde, Babcock-Wilcox water-tube boilers are being adopted.

The increasing cost of fuel, and the economy obtainable by the use of superheated steam, has tended to hasten development in that direction, and a fair number of ships, including the liner under construction, just referred to, are being fitted with superheaters. A saving of 10 to 15 per cent in fuel consumption has been shown to be possible, and it is likely that superheating will be much more widely adopted in the near future.

With regard to the gain in fuel economy, brought about by the developments which have taken place, it is difficult, owing to the varying factors involved, to state this in general terms. Average values, however, are given in the table opposite.

The problem of mechanical stoking, which has been successfully solved for the less severe conditions of land practice, still awaits solution as regards conditions afloat. Ideal conditions in this respect would be more easily reached by the extended use of liquid fuel, the advantages of which are obvious. Much progress has been made in perfecting apparatus for the proper combustion of oil, and its use would very rapidly be extended, but for the sufficient reason that the present relative prices of oil and coal are such as to make the use of oil for burning in furnaces, except in specially favorable instances, out of the question commercially. On the general economic question of the oil supply depends also the rate of future progress of the large internal combustion engine, the latest development in marine engineering.

The application of the internal-combustion engine to marine propulsion is no new development, small engines having been constructed for this purpose more than 20 years ago. During the last decade, however, rapid progress has been made with small engines using the lighter petroleum spirits and oils, and the extent to which the steam engine has been superseded in small craft, such as launches and pinnaces, is apparent. For this class of work the small weight and bulk of the internal-combustion engine and its general convenience are such as to make the steam engine almost obsolete. The problem of producing a reliable engine of the internal-combustion type of larger power, without undue complication of design, and sufficiently low in first cost and maintenance to be able to compete successfully with the steam engine or geared turbine, is a much more difficult one. Much experimental work has been done with this end in view, and there are many attractive possibilities.

Comparison of fuel consumption and weight of machinery, 1893–1913.

[For the same effective horsepower.]

Year.	Class of engine and boilers.	Relative fuel consumption.	Relative machinery weight.
	1. Atlantic passenger ships.		
1893	Twin-screw triple-expansion engine; cylindrical boilers	100.0	100.0
1913	Four-screw triple-series turbines; cylindrical boilers	90.0	81.0
1913	Four-screw triple-series turbines; water-tube boilers	94.0	60.0
	2. Intermediate liners.		
1893	Triple-expansion reciprocating engine; cylindrical boilers	100.0	100.0
1913	Quadruple-expansion reciprocating engine; cylindrical boilers	92.5	91.0
1913	Combination, reciprocating and turbine; cylindrical boilers	80.0	94.0
	3. Channel steamers.		
1893	Twin-screw triple-expansion engine; cylindrical boilers	100.0	100.0
1913	Three-screw direct turbines; cylindrical boilers	87.0	74 2
1913	Twin-screw geared turbines; cylindrical boilers	74.4	82.0
1913	Twin-screw geared turbines; water-tube boilers	76.0	60.0
	4. Cargo tramp steamers.		
1893	Single-screw triple-expansion engine; cylindrical boilers	100.0	100.0
1913	Single-screw triple-expansion engine; cylindrical boilers with superheater	85.4	100.0
1913	Single-screw geared turbines; cylindrical boilers	76.0	84.4

Comfort on shipboard has vastly improved during the past 20 years. Spring mattresses and brass bedsteads have replaced the old wooden bunks, improved systems of heating and ventilation have been introduced, sanitary arrangements are greatly superior both in quantity and in quality, while the furnishings of the public apartments and the attractions of the dining saloon vie with those of the finest hotels on shore. Third-class passengers have now separate cabins for four, six, or eight persons each, in place of large open 'tween-deck spaces filled with tiers of iron beds and accommodating hundreds. In place of benches and tables along the sides of the sleeping quarters, separate dining saloons, smoke rooms, and music rooms are provided.

Antirolling devices have been greatly developed. The use of free-water chambers, first suggested by Sir Philip Watts in 1875, and adopted in H. M. S. *Inflexible* and the *City of Paris*, has been reintroduced on an exact scientific basis by Mr. Frahm, while Mr. Schlick in Germany, and Mr. Sperry in America, have successfully applied the gyroscope to the reduction of rolling motions.

Wireless telegraphy, introduced in 1896, is now fitted in over 1,800 ships and 270 shore stations. By its agency each steamer can keep in direct touch with her sisters or with the shore. Already this power of communication over long distance has proved of inestimable value to vessels in distress by enabling them to summon immediate assistance. Wireless telegraphy is probably the greatest boon ever given to those in peril at sea.

As a preventive means, submarine soundsignaling has proved itself to be of immense value, especially where the mariner is surrounded by his most dangerous enemy, fog. It is well known that during fog both light signals and ordinary sound signals become very unreliable, whereas the state of the atmosphere has no effect upon sounds transmitted through the sea. The first submarine bell was installed in 1901, and to-day there are about 140 fixed bell stations and over 1,000 vessels fitted with listening apparatus.

The important questions of freeboard, subdivision, and lifeboat accommodation have all received a considerable amount of attention in recent years, and special committees have lately been appointed to investigate each of these intricate problems, so that nothing that human skill can devise may be left undone to secure the safety of human life and property intrusted to the vessels of our mercantile marine.

The 1892 bulkhead committee set as its highest standard the ability to remain afloat with any two adjacent compartments simultaneously flooded. The *Campania* was one of the first vessels to comply with the conditions laid down, and the *Scot* was also a " two-compartment " ship. Since that date not many ships have fully met the requirements, which were found in most cases to interfere too much with passenger and cargo facilities. The new *Empresses* on service in the Far East and the new Allan Liners have been made into " four-compartment " vessels, and it is more than probable that the new bulkhead committee will set a higher standard of safety than its predecessor.

One of the most appalling dangers at sea is that of fire, and in recent years many new systems of meeting this emergency have been introduced. The now universal replacement of candles and oil-illumination by electric light has eliminated one of the most frequent causes of conflagration, and should fire occur, systems of piping led into every part of the ship can quickly convey water, steam, carbonic-acid gas, sulphurous vapor, or the exhaust gases from the funnels so as to deprive the flames of the oxygen which is their life.

In the course of my remarks I have made no reference to failures, as these have been but rare among so many notable successes. Nevertheless much has been learned from failures, as each one, if read aright, indicates something to be avoided in future work. The solid progress recorded, with but little assistance from that manual labor which to-day claims to be the sole producer of wealth, has been the inevitable result of the persistent intellectual effort, amounting at times to genius, of the many men whose names are as household words among us and will live imperishably in the annals of our profession. It is impossible to review the history of marine construction without being forcibly impressed by the greatness of the debt we owe

to such men as James Watt, Scott Russell, Brunel, John Elder, Sir William Pearce, Sir William White, Dr. Elgar, the Froudes, the late Dr. Denny, and many others who have passed away, as well as to the Hon. Sir Charles A. Parsons and others who are still fellow workers with us. Active and daring minds have ever been questing forward, and no opportunity for advance, no probability of new development, has been allowed to pass without thorough sifting and examination. The needs of the coming years have been anticipated, the engineer has ever been in the van and not in the rear of material progress. We have seen how the ocean liner has steadily advanced in dimensions and speed. The only apparent obstacles to continued increase are those connected with finance and with the sizes of docks and harbors. In view of past experience, he would be bold indeed who would place any limit upon what the future will bring forth.

[The president, in moving a vote of thanks to the lecturer, remarked that his subject was a national question of vital importance. The growth of British oversea trade during the past 10 years had been phenomenal, having now reached, according to figures given by the First Lord of the Admiralty a few days ago, the enormous sum of 355,000,000 sterling per annum. Such figures indicated the great importance of the subject with which the lecturer had dealt so exhaustively, and he had the greatest pleasure in proposing a hearty vote of thanks to Mr. Gracie for his excellent and instructive lecture.

Sir John Wolfe Barry, K. C. B., past president, said he felt greatly honored at being allowed, as the seconder of the resolution, to ask the members to accord the vote of thanks which had been moved by the president. The record of the last 20 years which had been passed in review by the lecturer was one of gradual, sure, and extraordinary progress in shipbuilding. The " James Forrest " lecture for 1913 would be a record for all time of what had taken place during that period, and would remain as a landmark, as it were, of the progress and goal which had been reached by naval architects. For such records as that the members were indebted to their old friend, Mr. James Forrest, so long the secretary of the institution, who, with a happy inspiration, applied money given to him as a testimonial to the founding of lectures of high class; and whatever the particular branch of engineering with which a lecturer was invited to deal might be, the " James Forrest " lecture would, he thought, always hold a very high position as a record of what had been done in the various branches of engineering of which the institution was the representative body. The members of the institution were not merely railway builders, or dock makers, or shipbuilders, or electricians, for their spheres of work were manifold, and they were all joined together in one confraternity. For the happy inspira-

tion to which he had referred the members were indebted to their friend James Forrest, and he was sure the heart of many who recollected his sway would go out to him on the present occasion, when they heard the first "James Forrest" lecture that had been given in the theater of the new building. He was old enough to recollect some of the fathers of naval architecture, and he could not help casting his mind back far beyond the 20 years, which had been the purview of the lecture on the present occasion, to the much more distant years—the fifties and sixties—when the great pioneers of naval architecture were among them. He alluded in particular to their vice president, I. K. Brunel, who showed the way to the timid naval architects of the period. Although he was a widely educated engineer in every branch of his profession, he had a particular love for naval architecture, and showed how it was possible to design steamships which could make long voyages across the Atlantic when such an idea was scoffed at as chimerical. He did not think, on such an occasion, the members ought to forget the name of I. K. Brunel, the designer, in the first instance, of the *Great Western*, then of the *Great Britain*, and lastly of that extraordinary ship for her period, the *Great Eastern*, which had a tonnage of something like 17,000 or 18,000 tons, and was immensely in advance of any kind of naval architecture which had then been even dreamt of. He was also pleased to be able to recall the memory of his dear old friend, Mr. William Froude, who, he thought, rendered to naval architecture greater services than any other Englishman who ever lived, introducing science and exactitude into a profession which had been up to that time more or less empirical. He could not help recollecting those things, because, happy as the recollections of the last 20 years were, members should certainly not forget those great pioneers who showed the way 60 years ago; and he was sure they would all remember the luster of Brunel's achievements and look back with pleasure upon the remarkable success he achieved with the *Great Eastern*. It was important to bear in mind that that fine vessel, the *Great Eastern*, embodied almost all the principles which had been laid down by the lecture that evening as to strength of hull, watertightness, protection against accident, and the girder principle. That was a great achievement which should never be forgotten whenever naval architecture was under consideration at the present time.

Before sitting down he desired to be allowed to congratulate the members on being assembled for the first time in the present theater, and occupying their fine building during the first period of its existence. In congratulating everybody who was present as member, associate member, associate, or student, he could not help also thinking of the exertions which had been made by many people to bring about that very happy result. The members ought to be very grateful to

the building committee for the care and attention they had given to the plan of the building; they ought to thank the architect for all he had done; but he did not think they ought to forget the remarkable exertions which had been made by the secretary, Dr. Tudsbery, and his staff, during the four or five very strenuous years in which they were leaving the old building, housing themselves temporarily, and eventually transferring themselves to the present noble edifice. It pleased him immensely to be allowed that evening to say how grateful he was to Dr. Tudsbery and his staff, and to all who had been associated with the transfer of the institution from one great building to another.

He was sure the members would agree that Mr. Gracie had succeeded in laying before the institution a very interesting record of what had been done during the last 20 years. The lecturer was known as a past master in all that belonged to naval architecture, and the members wished to thank him very sincerely and cordially for coming among them that evening and delivering the first " James Forrest " lecture in the new building.

The resolution having been carried by acclamation,

Mr. Alexander Gracie, in acknowledging the vote of thanks, said that the patience with which the members had listened to him, together with the compliment that the institution had paid him by asking him to deliver the lecture, was more than ample reward for anything he had done.]

CREATING A SUBTERRANEAN RIVER AND SUPPLYING A METROPOLIS WITH MOUNTAIN WATER.[1]

By J. Bernard Walker and A. Russell Bond.

[With 11 plates.]

I. CREATING A SUBTERRANEAN RIVER 90 MILES IN LENGTH.

By J. Bernard Walker.

PHENOMENAL GROWTH OF NEW YORK.

Greater New York is adding to its population at the rate of 140,000 people per year—an increase which is absolutely without precedent or parallel in the growth of the world's great cities. Such an increase as this renders enormously difficult the problems of housing, food supply, transportation, and proper hygiene. For many years past, and long before the rate of increase had reached its present proportions, the city authorities have been at their wits' end in endeavoring to enlarge the various facilities of the city so as to keep pace with the demands of its ever-growing population.

THE PERIL OF WATER FAMINE.

With the exception of rapid transit, there is no problem of the city's need which has proved more serious, more pressing or more difficult, at least in recent years, than that of providing an adequate supply of pure drinking water. At frequent intervals the city has been threatened by that justly dreaded terror, a water famine— justly dreaded, because a shortage, to say nothing of a total failure, of water might mean an outbreak of pestilence, to say nothing of the loss and inconvenience occasioned by the shutting down of the various factories and smaller industries which a shortage of the water supply would necessitate.

It is not so very many months since the whole city was watching, with a very anxious eye, the steady fall of the water levels in the various reservoirs of the Croton watersheds; for a season of drought, extending far into the winter, had served to bring the hitherto remote peril close to its very doors.

In view of the rapid growth of the city, it was evident at the outset that any adequate scheme for increasing the water supply must

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be made upon the broadest possible scale; and that it should make
provision, not only for the immediate needs of the city, but for
those of many a decade to come. This has been done by the board
of water supply; and it is the purpose of this and the following
article to show that the project of bringing the Catskill Mountain
water to New York has been considered on such adequately com-
prehensive lines that the possibility of any shortage of water in this
great city has been removed into the very far future.

On May 14, 1906, the State water supply commission approved
of the application of the board of water supply of this city for ob-
taining a daily supply of 500,000,000 gallons of water from the
Esopus, Rondout, Schoharie, and Catskill Creeks in the Catskill
Mountains, at an estimated cost of $161,867,000. In 1910 a plan
for the distribution of the water throughout Manhattan, Queens,
and the Bronx by a deep-pressure tunnel was approved by the board
of estimate and apportionment. The additional cost of this scheme
is $15,000,000.

THE NEW SCHEME OF WATER SUPPLY.

The new supply of water, of the finest mountain quality, is to be
taken from four watersheds, having a total area of nearly 900 square
miles. The total estimated capacity of these four gathering grounds
is, even in a series of unusually dry years, equal to supplying 770,-
000,000 gallons daily. Reservoirs will be built, as they are required,
in each of these basins, and they will be connected by aqueducts. For
the present, the Esopus watershed only is being developed. In a
series of dry years this watershed can furnish a daily supply of only
250,000,000 gallons; but the aqueduct leading to the city is being
built of double that capacity or 500,000,000 gallons daily. The first
contract for construction was let at the close of 1906. In 1907 to 1908
about 5 per cent of the work was completed from Ashokan reservoir
in the Esopus watershed to Croton Lake. By the end of 1909, 22
per cent was done, 60 per cent at the close of 1910, 78 per cent by
1911, and at the present time about 95 per cent of the work is done.
The delivery of water into the Croton Reservoir, which will be pos-
sible this year, will prevent any possibility of water famine during
the completion of the new aqueduct to New York.

The system under construction and now nearing completion con-
sists of a large reservoir in the Esopus Basin, an underground aque-
duct 17 feet in diameter by which the water is led for 64 miles to an-
other large basin, the Kensico Reservoir, which will serve for emerg-
ency storage; a third reservoir situated about 15 miles south of Ken-
sico and just over the New York city line, known as the Hill View
Reservoir, which will equalize the difference between the use of water
in the city, which, of course, varies from hour to hour and from day

to day, and the steady flow coming in from the aqueduct. Between Hill View and the city the system consists of a deep circular, high-pressure tunnel, through which the water will be led beneath Manhattan, to be distributed by surface mains throughout that city, and also throughout the other districts of Greater New York.

THE ASHOKAN RESERVOIR.

The great Ashokan Reservoir is situated about 14 miles west of Kingston, on the Hudson River. Its cost is $18,000,000, and it will

CUT AND COVER AQUEDUCT
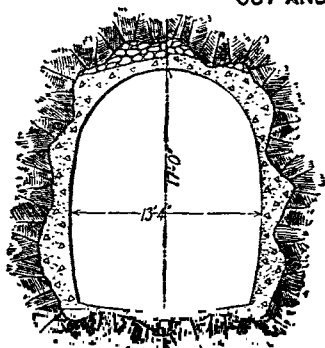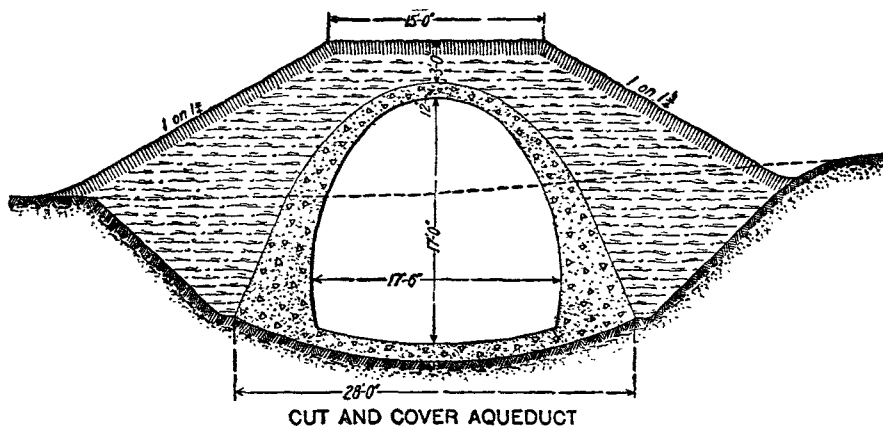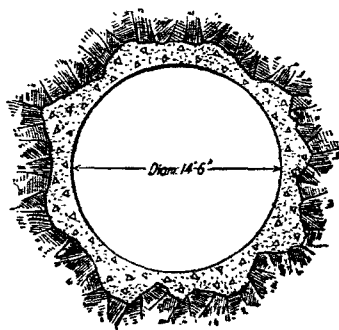
GRADE TUNNEL   **PRESSURE TUNNEL**

hold sufficient water to cover the whole of Manhattan Island to a depth of 28 feet. The water is impounded by the Olive Bridge Dam, which is built across Esopus Creek, and also by the Beaver Kill and the Hurley dikes, which have been built across streams and gaps lying between the hills which surround the reservoir. By the 1st of January, this year, 73 per cent of this work was done. The dam is a masonry structure 190 feet in thickness at the base, and 23 feet thick at the top. The surface of the water when the reservoir is full is 590 feet above tide level. The total length of the main dam

is 4,650 feet, and the maximum depth of the water is 190 feet. The area of the water surface is 12.8 square miles, and in preparing the bottom it was necessary to remove seven villages, with a total population of 2,000. Forty miles of highway and 10 bridges had to be built. In the construction of the dam and dikes it was necessary to excavate nearly 3,000,000 cubic yards of material, and 8,000,000 cubic yards of embankment and nearly 1,000,000 cubic yards of masonry had to be put in place. The maximum number of men employed on the job was 3,000.

THE 92-MILE AQUEDUCT.

The water is conducted from Ashokan Reservoir as a huge underground artificial river. The aqueduct is 92 miles in length from Ashokan to the northern city line, and it should be explained that it is built on a gentle grade, and that the water flows through this at a slow and fairly constant speed. The aqueduct contains four distinct types: The cut-and-cover, the grade tunnel, the pressure tunnel, and the steel-pipe syphon. The cut-and-cover type, which is used on 55 miles of the aqueduct, is of a horseshoe shape and measures 17 feet high by 17 feet 6 inches wide, inside measurements. It is built of concrete, and on completion it is covered in with an earth embankment. This type is used wherever the nature of the ground and the elevation allow. Where the aqueduct intersects hills or mountains it is driven through them in tunnel at the standard grade. There are 24 of these tunnels, aggregating 14 miles in length. They are horseshoe in shape, 17 feet high by 13 feet 4 inches wide, and they are lined with concrete. When the line of the aqueduct encountered deep and broad valleys, they were crossed by two methods: If suitable rock were present, circular tunnels were driven deep within this rock and lined with concrete. There are 7 of these pressure tunnels of a total length of 17 miles. Their internal diameter is 14 feet, and at each end of each tunnel a vertical shaft connects the tunnel with the grade tunnel above. If the bottom of the valley did not offer suitable rock for a rock tunnel, or if there were other prohibitive reasons, steel siphons were used. These are 9 feet and 11 feet in diameter. They are lined with 2 inches of cement mortar and are imbedded in concrete and covered with an earth embankment. There are 14 of these pipe siphons in a total length of 6 miles. At present one pipe suffices to carry the water. Ultimately three will be required for each siphon.

Of the many siphons constructed, by far the most interesting and difficult is that which has been completed beneath the Hudson River. The preliminary borings made from scows in the river showed that great depths would have to be reached before rock sufficiently solid and free from seams was encountered to withstand the enormous hydraulic pressure of the water in the tunnel. After failing to

PLATE 1.

OLIVE BRIDGE DAM. ESOPUS CREEK FLOWING THROUGH TEMPORARY TUNNEL.
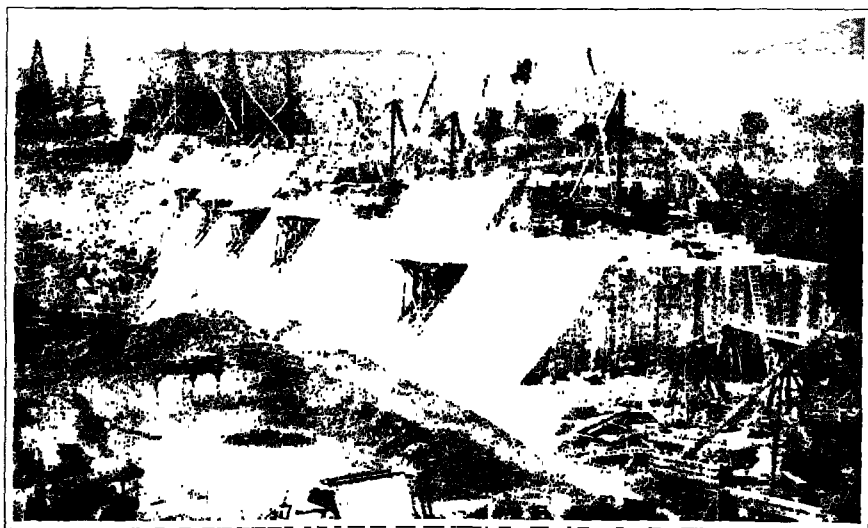
BUILDING OLIVE BRIDGE DAM TO FORM THE ASHOKAN RESERVOIR.

PLATE 2.
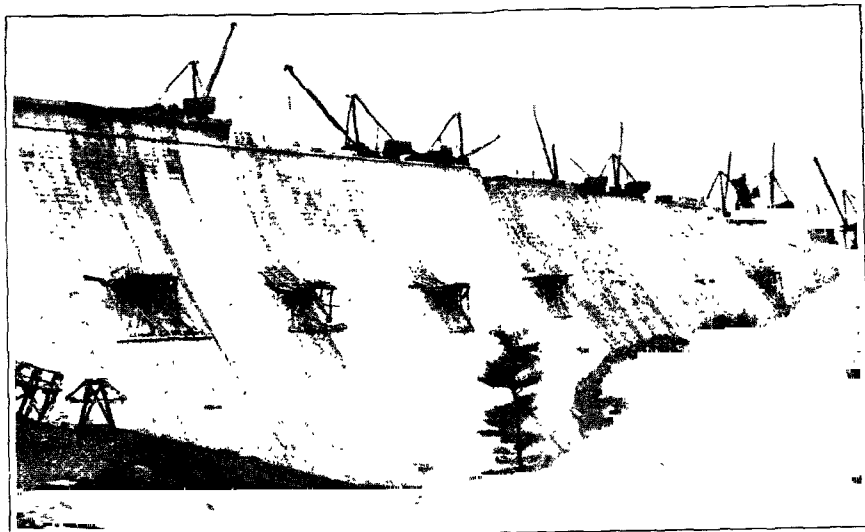
THE OLIVE BRIDGE DAM, 4,650 FEET LONG, 220 FEET HIGH.

IN THE HUDSON RIVER SIPHON, 1,100 FEET BELOW THE RIVER.

reach rock by the scow drills, two series of inclined borings were made from each shore, one pair intercepting at about 900 feet depth and the other at about 1,500 feet. Both showed satisfactory rock; and accordingly a shaft was sunk on each shore to a depth of approximately 1,100 feet, and then a horizontal tunnel was driven connecting the two. It is of interest to note that because of the enormous head, which must be measured from the flow line far above the river surface, the pressure in the horizontal tunnel reaches over 40 tons per square foot.

TYPICAL SECTION OF DIKE

OLIVE BRIDGE DAM
MAXIMUM MASONRY SECTION

STEEL PIPE SIPHON
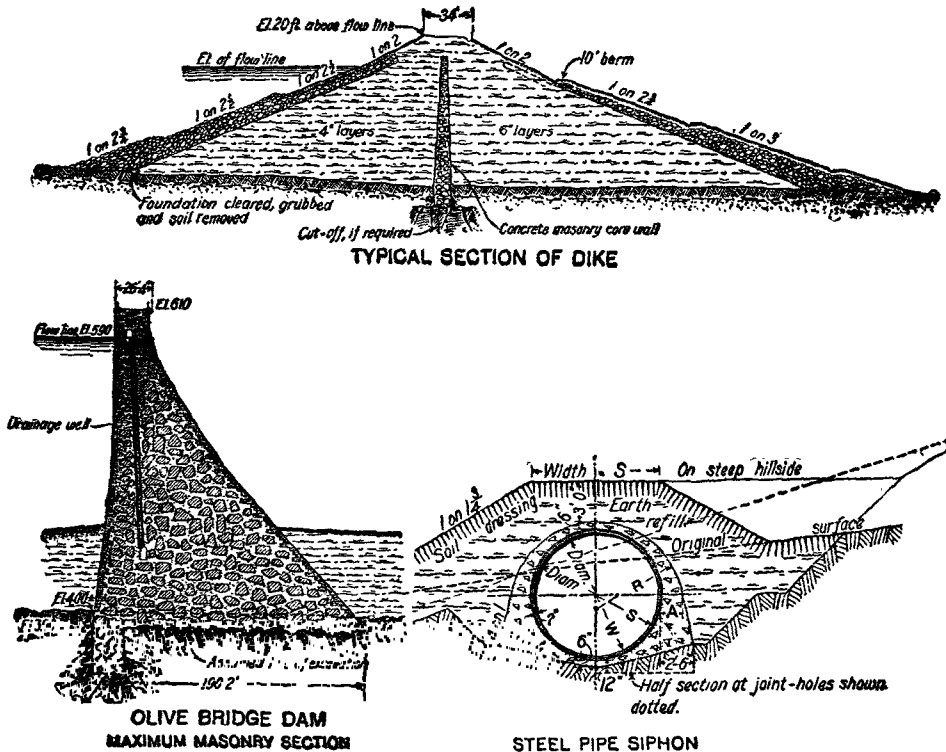
KENSICO RESERVOIR.

Next to Ashokan the most important basin is the Kensico reservoir, which lies east of the Hudson, and is situated 30 miles north of the city hall. It will hold sufficient of the Catskill water to supply the city for several months. Its purpose is to act as an emergency storage reservoir, so that if it is necessary, on account of accident, to interrupt the flow in the 77 miles of aqueduct between Kensico and Ashokan, this can be done without interrupting the city supply. The cost of this work is $8,500,000.

The reservoir will be formed by a huge masonry dam across the valley of the Bronx River. The surface of the water will be at an

CATSKILL WATERSHEDS AND AQUEDUCT

MAP SHOWING CATSKILL AND CROTON WATERSHEDS AND THE AQUEDUCT.

PLATE 3.
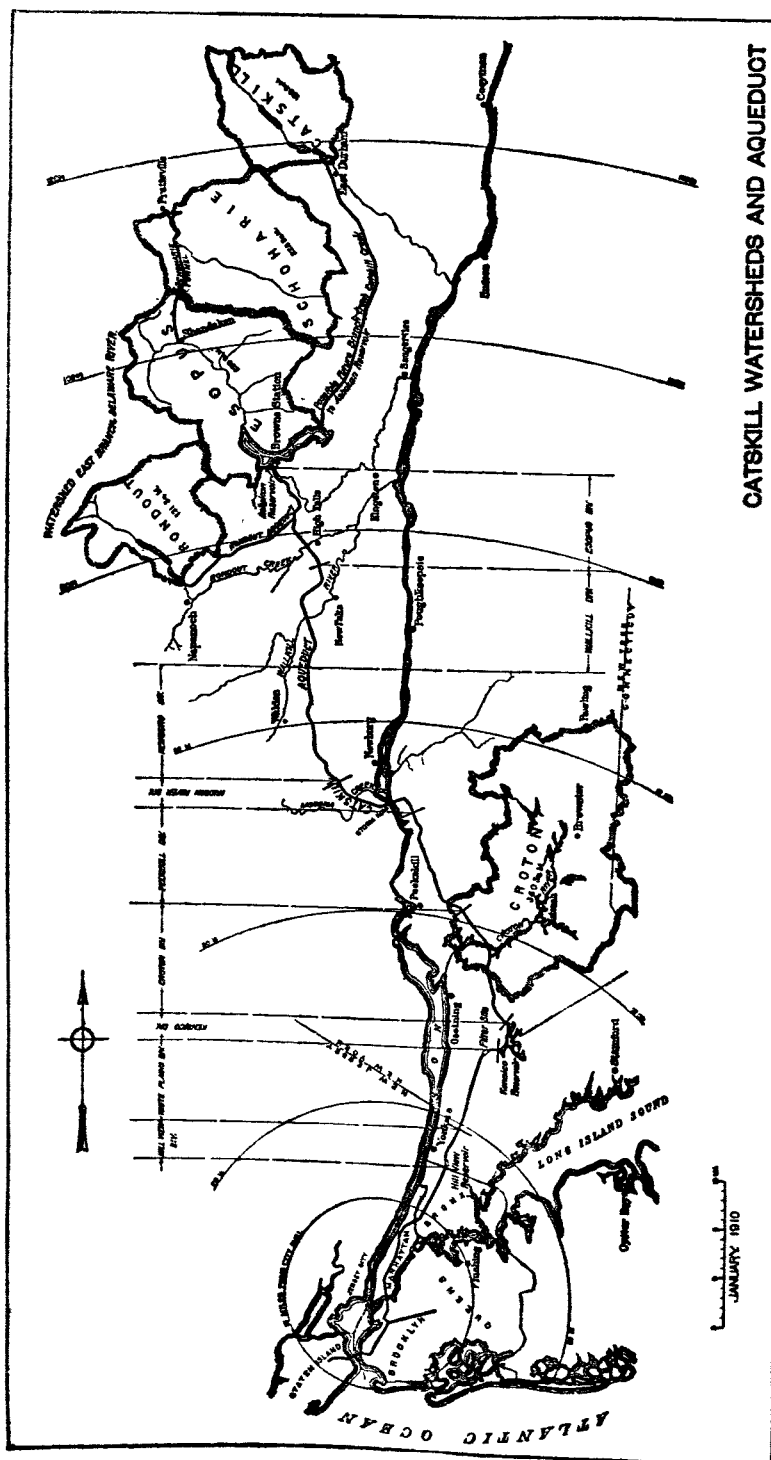
PLACING THE 9½ FOOT STEEL PIPES—FOUNDRY BROOK SIPHON.

immediate demand, such as occurs during a great conflagration. Its capacity will be 900,000,000 gallons. The reservoir is divided into two basins, so that one may be used while the other is being inspected for repairs. The aqueduct is carried within the wall which divides the two basins, and the aqueduct water can be passed through the reservoir and delivered directly into the city tunnel.

Our thanks are due to Mr. Alfred D. Flinn, department engineer of the board of water supply, for courtesies extended during the preparation of this article.

II. SUPPLYING A METROPOLIS WITH MOUNTAIN WATER.

By A. RUSSELL BOND.

HOW MINING OPERATIONS ARE BEING CARRIED ON THROUGH THE HEART OF NEW YORK.

The preceding pages tell how the new aqueduct is being constructed from the Catskill Mountains down to the New York City line, where, at the Hill View Reservoir, the waters will pause before taking their plunge into the heart of the city.

The problem of admitting so large a flood into the metropolis is no small one, particularly when the chief demand for the water will come from those sections of Greater New York which lie many miles away. For the present, at least, little if any of the Catskill water will be used in Manhattan and The Bronx, but most of it will be consumed by the boroughs of Brooklyn, Queens, and Richmond. The water-waste campaign which has been carried on for the past few years has so far reduced the consumption of water that the Croton system, which can furnish steadily 350,000,000 gallons of water per day, can easily take care of the immediate wants of Manhattan and The Bronx as well as the demand from these two boroughs for many years to come. It is not likely that the population in Manhattan will increase much, unless it undergoes a marked vertical growth, for now there are practically no more vacant lots to be built upon. So that in estimating the future demands upon the Croton system, we must consider chiefly the growth of population in The Bronx. In the other three boroughs of the city, however, there is a present demand for water, and the probability of large increases in population in coming years.

To conduct the Catskill water into Brooklyn and Queens, it was decided to build a trunk line so far beneath the surface that there would always be 150 feet of good, solid rock for the roof of the tunnel, and provide a course for a subterranean river which could be tapped as needed for the city's supply, and which at the same time would be so completely buried that it would never menace the safety
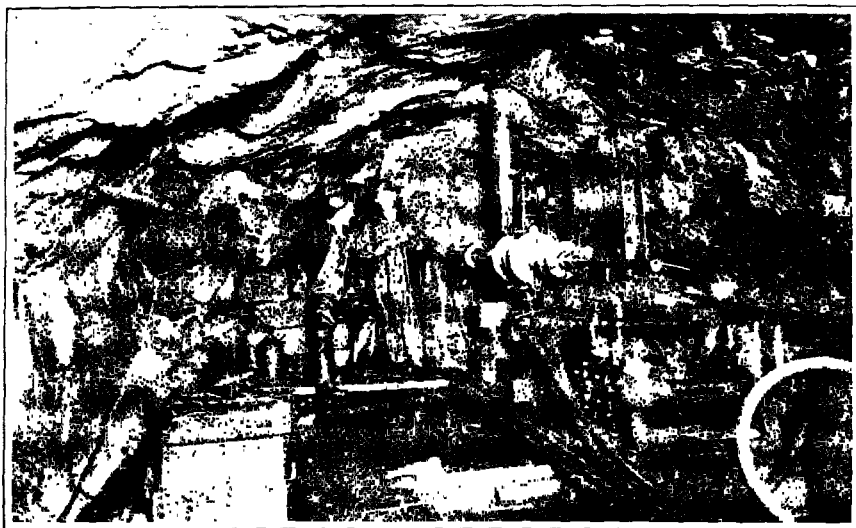
DIAMOND DRILL BORING HORIZONTAL HOLE 1,100 FEET BELOW HUDSON RIVER.
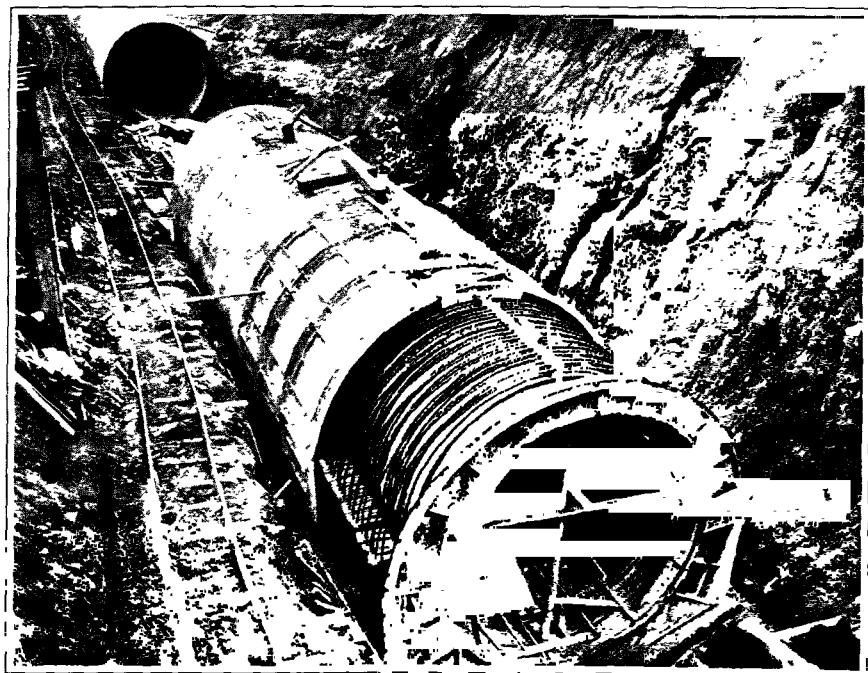
CONSTRUCTING A STEEL AND CONCRETE SECTION OF AQUEDUCT.

This section consists of a steel pipe lined internally with 2 inches of cement mortar, and embedded in reinforced concrete.

DYNAMITE CHAMBER.

Note the roof over the shelves.
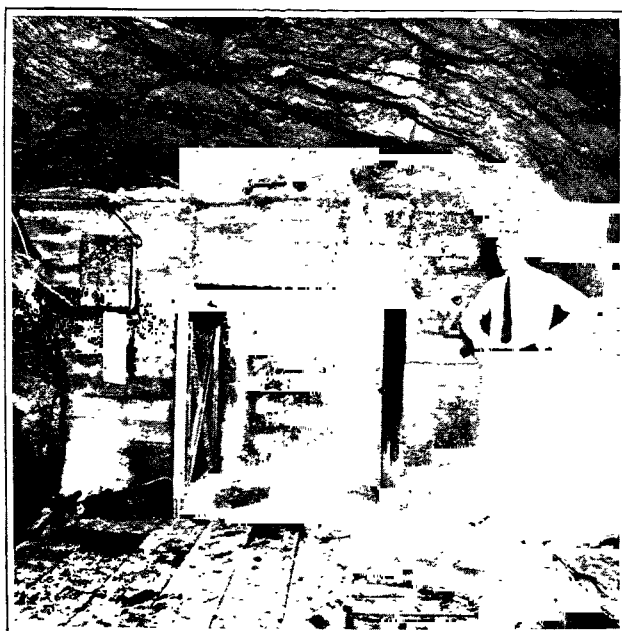
MAGAZINE DOOR, WHICH CLOSES AUTOMATICALLY IN CASE OF EXPLOSION.

of structures above it. When the tunnel is completed, it will be one of the most durable pieces of work ever constructed by man; for practically nothing but an earthquake can destroy it, and even this possibility is very remote, for the rock underlying New York is of very early formation, and not at all liable to seismic disturbance. And so the city tunnel of the Catskill aqueduct is being bored through the rock on an average of 200 to 250 feet below the surface, except in places where the nature of the rock is of such a character as to call for a much greater depth.

The first dip takes place just above the Harlem River, where the tunnel drops down to 362 feet below the ground level. Then it runs practically horizontally until it passes the dip in the rock under One hundred and twenty-fifth street. Thence it rises again, and maintains a practically constant level of 200 feet under the city until it arrives at the ancient bed of the East River. A glance at the map of New York City will show that the East River makes a decided turn about the lower east side or " heel " of Manhattan. In preglacial times the East River had no elbow in its course, but ran directly across the heel of Manhattan, and it wore away the rock in its bed to considerable depths. However, the large deposits of earth and rock carried by the glaciers caused the river to be pushed eastward, out of its normal channel and over the solid rock beyond. When borings were made for the aqueduct through this section of the city, it was found necessary to lay it at a depth of about 750 feet below the surface. As indicated in the drawing on page 721, much of the rock through this section is decayed and unfit to form the walls of a high-pressure aqueduct which is being built to last for all time. The present channel of the East River, on the other hand, passes over solid rock, and is comparatively shallow. Seven hundred and fifty feet is an enormous depth, second only to the great siphon under the Hudson River, which is 1,114 feet below the river surface. It so happens that the deepest shaft ever sunk in New York City equals the height of the tallest building in the world. To illustrate this enormous depth, our artist has taken the liberty of building the Woolworth Building topsy-turvy—that is, from the ground down— at the Clinton Street shaft at the west bank of the East River. Enormous as is the building, yet it barely reaches the aqueduct at this point. Evidently there will be plenty of cellar room over the tunnel; and yet it is worth noting, the aqueduct follows the street lines so as not to trespass on private property.

Arrived in Brooklyn, the aqueduct rises again to within two or three hundred feet of the surface and is pushed as far as it is possible to carry it in solid rock and yet communicate with the surface. This limit was found to be at the junction of Flatbush and Third Avenues.

Here it was necessary to go through 215 feet of overlying earth before coming to the rock. The caisson method had to be resorted to, and the caisson was sunk over 100 feet below the water line before rock was reached. Considerable difficulty was here experienced in sinking the shaft to the rock, because it called for the use of pneumatic pressure that taxed the endurance of the workmen to the limit. From here on the water will be conducted through pipes laid in a trench of a moderate depth below the surface. From the foot of Seventy-ninth Street, Bay Ridge, the conduit will be run across the Narrows to Staten Island, through a pipe 36 inches in diameter, provided with flexible joints, and laid in a submarine trench. The details of this section of the work have not yet been given out. However, tests have been made to discover at what depth the pipe line under the water must be buried. It is evident that it must lie far enough below ground to prevent its being entangled with anchors from large vessels that may have to anchor in the Narrows. The matter has been thoroughly investigated, and practical tests have been made by dragging anchors of large size along the bottom. It has been determined that if the pipe line is buried at least 8 feet under the bed, it will be entirely safe. On the Staten Island side a 48-inch pipe will carry the water on up the hill and through a tunnel into Silver Lake Reservoir, 120 miles from the source in the Catskills.

The greatest interest in this city section of the aqueduct attaches naturally to that part which is being excavated through solid rock under the busy city. It is a surprising fact that a work of such magnitude can be carried on directly under our feet without inconveniencing us in the least. The only surface evidence of the deep rock tunneling is to be found at the various shafts which are located in parks or public squares. The principal difficulty that presented itself at first was the question of storing explosives for a work of such great proportions. To keep the necessary explosives on the surface was to harbor constant menaces to the lives of the citizens. The matter was finally solved by placing the dynamite magazines far under the surface in the rock, and setting the doors to these magazines so they will automatically close in case of an explosion and trap the hot and poisonous fumes in the rock chamber, where they can do no harm to the workmen. The idea was borrowed from European practice, where mining operations are conducted close to and sometimes directly under large cities. Access to the dynamite chamber is had through a zigzag drift. At each turn of the drift a pocket is excavated, and the chamber itself is made of large capacity. In this chamber the dynamite is stored under a protecting roof to keep off any fragments of rocks that might fall when jarred by the "shooting" in the tunnel. At the entrance of the drift a very substantial concrete bulkhead is built, and in this is a low doorway. The door is
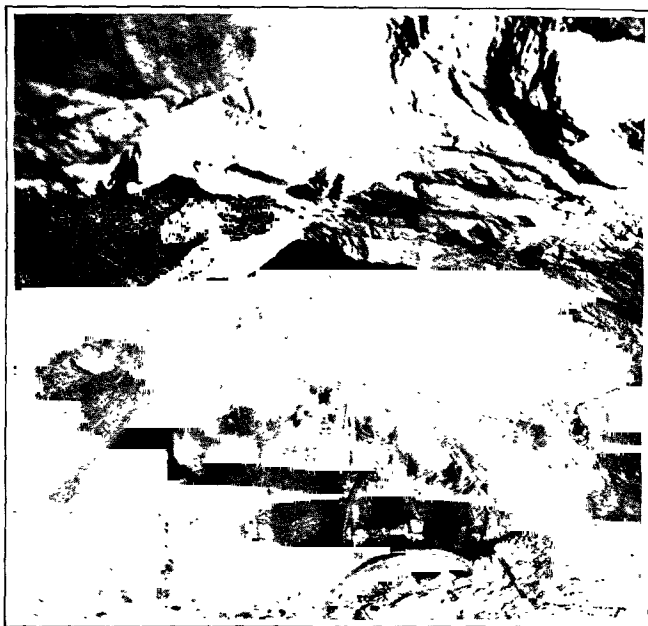
DRILL POSTS SET UP AT A TUNNEL HEADING, TWO DRILLS ON EACH POST.
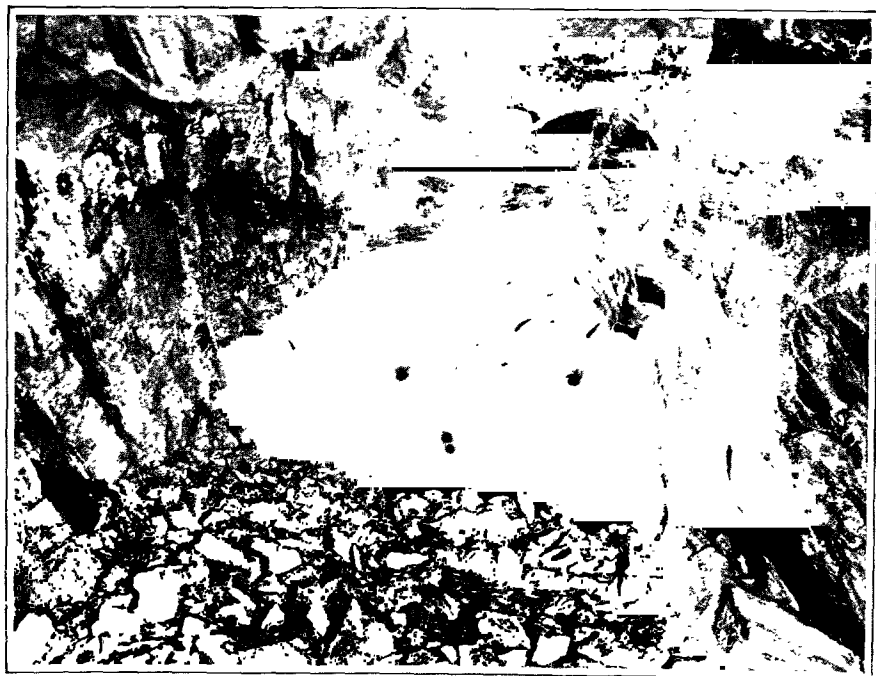
"HOLED THROUGH" FROM SHAFT 16 TO SHAFT 17. DANGEROUS ROCK OVERHEAD DUE
TO VERTICAL SEAMS.
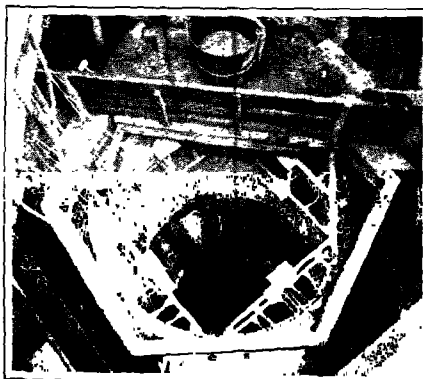
LOOKING DOWN THE 441-FOOT SHAFT AT
ONE HUNDRED AND FORTY-NINTH STREET.
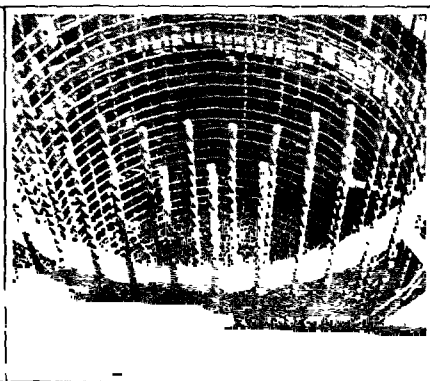
REINFORCEMENT FOR THE CAISSON AT FLAT-
BUSH AND THIRD AVENUES.

PERMANENT CHANNEL IRON SUPPORT FOR A TREACHEROUS ROOF. THE BEAMS WILL
BE IMBEDDED IN THE CONCRETE LINING.

of massive construction, built of I-beams, 16 inches deep and spaced apart with oak beams 12 inches square. The door has beveled edges, so that it will seat itself snugly in the doorway. The door is always kept open at an angle of about 45°. In the magazine a thousand pounds of dynamite may be kept at a time. Should this be exploded, the explosion wave would have to travel down the zigzag passage and would lose much of its force at each abrupt turn, finally striking the door with greatly diminished energy. The door would be slammed shut by the blast of air issuing from the drift and would then be held shut by the gases of the exploded dynamite. A magazine of this sort has been constructed near the foot of each shaft—not *at* the foot, however, for fear that in case of a mishap, it might block the escape of the men. The magazines have been tested by exploding a number of sticks of dynamite around the first bend in the drift, and in every case the door has closed just as expected.

The work through the rock is being pushed very rapidly; at some of the shafts between 800 and 1,000 pounds of dynamite have been used daily. Within the last year millions of pounds of dynamite have been exploded under the city, while most of New York was totally oblivious to the fact. Already a number of the tunnel sections have been "holed" through. To expedite the work, one contractor is using an interesting form of shoveling machine, built especially for this work, so that it may be taken down the comparatively narrow shaft and be assembled to work within the small diameter of 11 feet, which is the size of the tunnel at the particular point where this machine is now being used. A photograph of this machine is shown herewith, and also a drawing illustrating the mechanism (pl. 10). The machine is controlled by a single operator and does the work of six laborers. It is provided with a double shovel A and B. The section A digs up the rock and throws it upon the scoop B, which in turn empties its load upon a traveling chain conveyor C; the latter delivers the load into muck cars at the back of the shoveling machine. The letters B, B^1, B^2, and B^3 show the successive positions of the scoop. The forward section A is carried upon a crank shaft D, which is revolved through the arc indicated by the arrow. Another arrow line shows the course of the front edge of the section A. The forward end of the scoop B rests upon the heel of the section A, while its rear end is mounted upon a shaft E, which travels in a guideway F. The forward section A is connected to the shaft E by means of side plates, indicated by dotted lines, so that as the crank shaft D revolves, the slide shaft E is obliged to run up the ways F, as indicated by the letters E^1, E^2, and E^3. The section B is equipped with a small arm G, which carries a roller that is adapted to engage the cam groove H, causing the scoop B to turn over as indicated in the dotted view B^3, and empty its load upon the travel-

ing conveyor. The machine is mounted on a turntable so that it may be turned about in any direction.

Some of the work on the city pressure tunnel has been hurried so far that certain sections are now being lined with concrete. The forms used for this purpose are very interesting. Our illustration, plate 11, shows their construction. They cover 120 feet altogether and are arranged in two sections, 60 feet of the lower half of the tunnel being concreted in advance of 60 feet of the upper part. The first step is to lay the " invert;" that is, a narrow segment of the lining running along the bottom of the tunnel. This, when completed, forms the track upon which the forms for the rest of the lining travel. The forms are mounted on trucks with wheels tapered to fit the curve of the invert. The forms for the lower half cylinder are practically the same as those for the upper half cylinder. After the lining has set, the sides of the upper form may be drawn in to free them from the concrete by operating the turnbuckles A, and those of the lower forms by operating the turnbuckles B. Then jacks may be unscrewed to lower the upper section slightly, freeing it completely from the concrete, and jacks E may be screwed up to raise the bottom section slightly upon the truck. In this collapsed condition the forms may be drawn forward to complete the next section of tunnel. The detail view in the drawing (pl. 10, fig. 2) shows how the lower forms are supported on the trucks. To the longitudinal beams C, vertical guides D are bolted, which fit against the framework of the truck. The jacks E mounted on the truck bear against cross pieces running from C to C. The filling of the lower half of the forms is comparatively simple. It is quite a different task, however, to lay the concrete into the upper form. Sections of the plating of the upper forms are removed and the concrete is shoveled in, adding the plates step by step as necessary, until finally the topmost plate is added, when the concrete can be introduced only from the end of the form. It will be observed that small pieces of board are temporarily nailed against the edge of the forms and fitted up as neatly as possible against the rock above, so as to retain the concrete until it sets. As each section is completed, grouting holes are left in the top through which, when the lining is completed otherwise, grout will be forced under high pressure to fill up all cracks and crevices and make the lining perfectly sound.

At each shaft access will be had to the tunnel through risers or vertical pipes, 48 or 72 inches in diameter. At most of the shafts two such pipes will be provided, each fitted with valves at the bottom, which may be operated from the surface to close either of them when it is desired to gain access to them or to effect any necessary repairs. The valves at the bottom of the risers will be of such a design as to
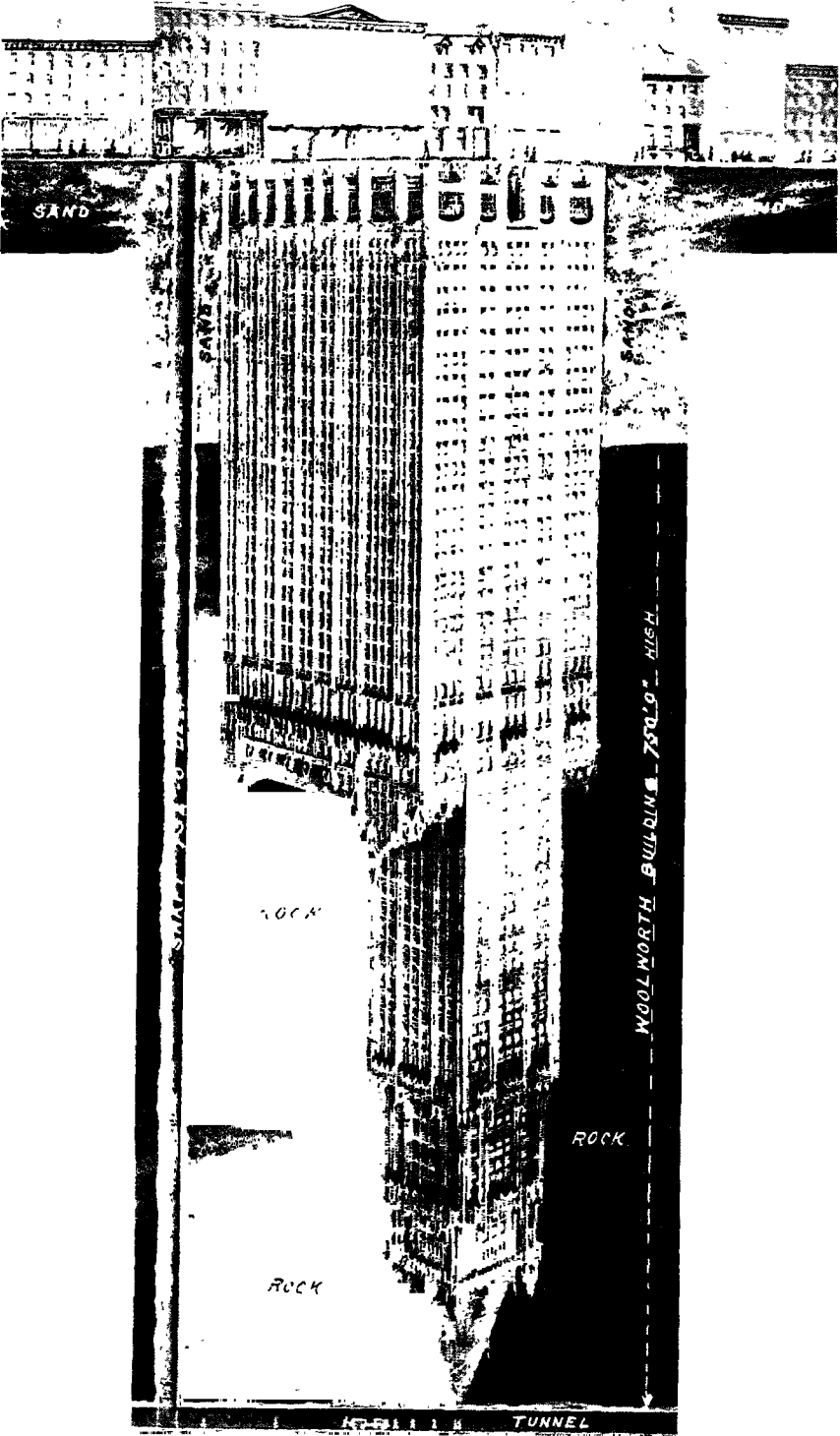
HEIGHT OF WOOLWORTH BUILDING EQUALS DEPTH OF
DEEPEST AQUEDUCT SHAFT IN NEW YORK
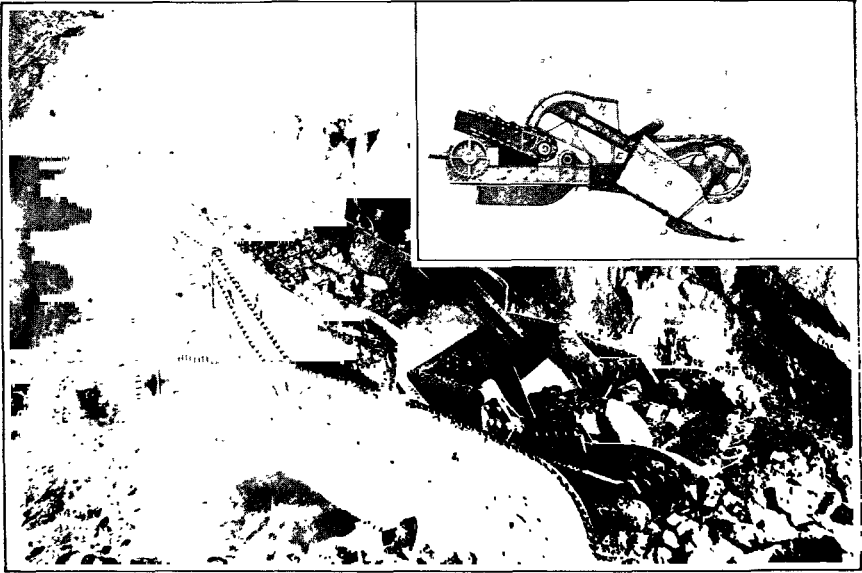
FIG. 1.—SHOVELING MACHINE FOR REMOVING THE BROKEN ROCK AND LOADING IT INTO CARS.
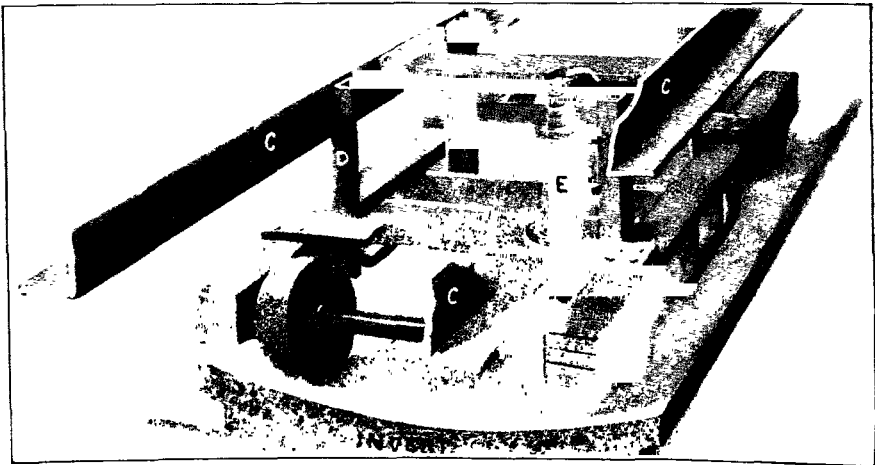
FIG. 2.—TRUCK FOR CARRYING STEEL FORMS FOR CONCRETE LINING.

PLATE 11.
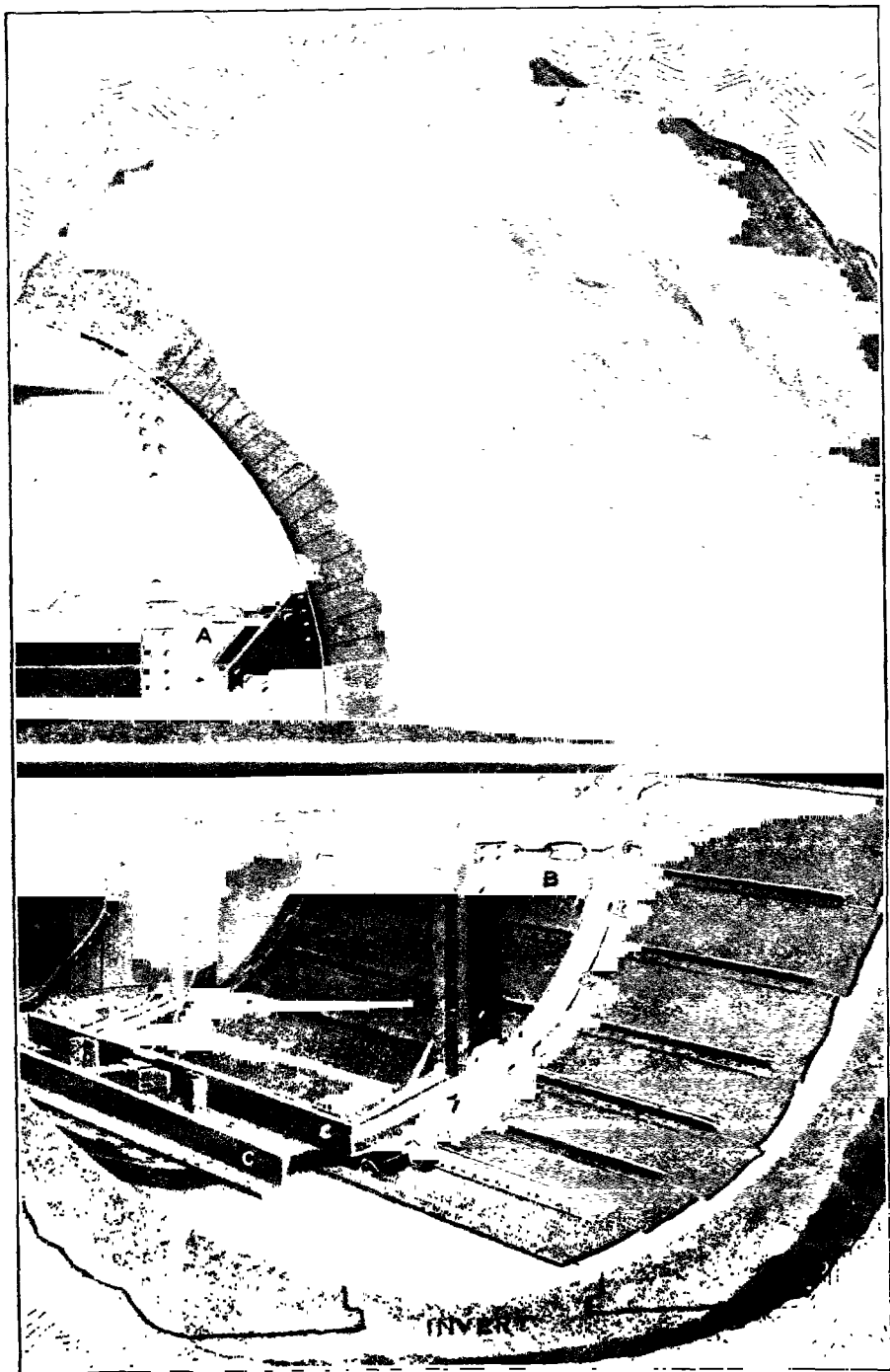
STEEL FORMS USED IN LINING THE AQUEDUCT WITH CONCRETE.

close automatically in case of an abnormal flow through the risers, due to the destruction of the valve at the top by explosion or other accident. At the top of the risers there will be two valves, the one nearer the riser being an emergency valve, which may be closed in case of any damage to the other valve.

It is probable that no immediate changes will be made in the water supply of Manhattan and Bronx, except that pipe lines will be run from the shafts to help out the existing supply in case of emergency. In Brooklyn and Queens, where 35 pumping stations are now required, most of the stations will be discontinued for the reason that the water will be delivered through the aqueduct at sufficient pressure to reach practically all parts. Only in one or two sections will pumping be necessary.

From Hill View Reservoir the water will flow through a tunnel 15 feet in diameter. This will be narrowed to 14, 13, 12, and 11 feet, which is the diameter of the rock tunnel at Fort Greene Park, Brooklyn, and at the intersection of Flatbush and Third Avenues. From there on steel pipes, $5\frac{1}{2}$ feet in diameter and running down to 4 feet in diameter, will carry the water to the Narrows, and under New York Bay, at the Narrows, the line will be only 3 feet in diameter. This gradual shrinking of the aqueduct reminds one of those large rivers that flow out of the mountains in sufficient volume to be navigable and even a menace to the surrounding country in time of flood, but which, when they reach the deserts, are drunk up by the thirsty sands and sucked by the torrid sun until they vanish without any clearly defined terminus or possibly flow in a sickly stream to a small stagnant lagoon. Thus, when the entire Catskill system is completed
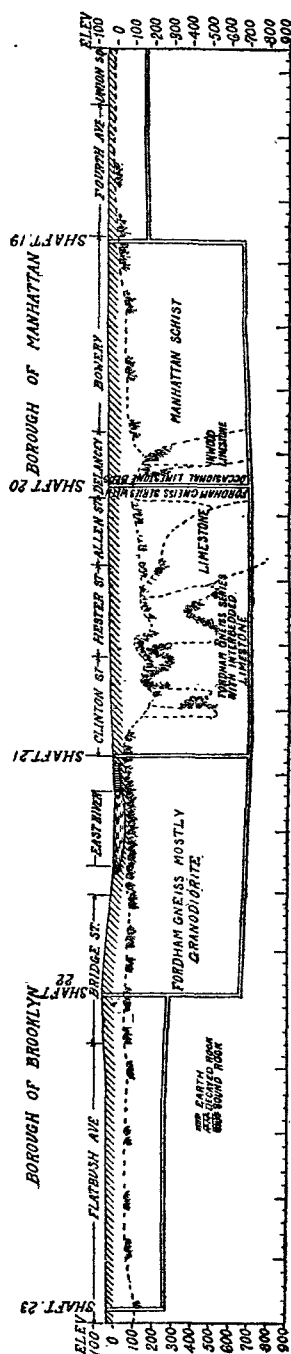
Section along the city pressure tunnel, showing how it has to dip down under the pre-glacial bed of the East River.

and operating at its full capacity, the waters which three days before poured out of the Ashokan Reservoir in a mighty flood, over 17 feet in diameter, will reach Staten Island a stream only 3 per cent of its former size, after having been robbed by the rest of the thirsty city.

THE APPLICATION OF THE PHYSIOLOGY OF COLOR VISION IN MODERN ART.[1]

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Leonardo in his treatise on painting says:

Those who become enamored of the practice of the art without having previously applied themselves to the diligent study of the scientific part of it, may be compared to mariners who put to sea in a ship without rudder or compass, and, therefore, can not be certain of arriving at the wished-for port. Practice must always be founded on good theory.

Instead of serving as an incentive to more extensive study of the use of colors in art, these words seem to have marked the advent of an epoch extending over several centuries, during which colors came to be less and less successfully employed. The ideals of art came to be dictated by the academic painter and they were much more mythological and allegorical than founded on the beauty of color patterns. Much of art became black painting, little attempt being made to use pure colors and no consideration being given to the effects which could be produced by the influence of juxtaposed colors on one another. With the exception of some masters the ideal of artists was merely to reproduce as closely as possible the color tones and values as seen in nature—to produce a colored photograph without adding to it that mysterious something for which is responsible the peculiar charm and strength of the paintings of the early Italian masters and of the Chinese and Japanese, and which includes some subtile influence of the picture itself quite apart from what it represents; something that endows it with a charm that is all its own, and which no colored photograph can ever contain.

It is true that from time to time in the history of modern art masters have arisen who have, intuitively as it were, produced pictures the color schemes of which have contained this "something." But it is the individual rather than the system that has been responsible, and no attempts have been made until comparatively recently

to evolve new principles for the use of colors which would serve as a guide to all; nor, indeed, was such an evolution possible until some progress had been made in the scientific interpretation of color. This progress is itself only of comparatively recent date.

At the present day there is an unrest in the world of art, an unrest which has resulted in the creation of innumerable schools, each endeavoring by some peculiar method of its own to inculcate new principles and to establish new ideals. Within a short period of time realism has given place to impressionism, impressionism to post-impressionism, and this again has become parent for so many other " isms " that to follow them has become almost impossible. However unpictorial from our ordinary viewpoint the creations of some present-day artists may appear to be, there is nevertheless in many of them some newly discovered truth; they are the steps in an evolution, and we may hope that some day the evolution will be consummated and that from out of the apparent chaos which at present exists a really compelling picture will be created.

It is most of all in landscape painting that the evolution of modern art can be seen. The old landscapes of Claude Lorrain and Constable are no doubt full of charm, but they entirely lack the atmosphere and force of the so-called impressionist paintings of Monet, Sisley, Pissaro, etc. In the older landscapes an attempt was made to copy everything that could be seen by prolonged study, and the canvas was covered with detail to its very edges; in impressionism it is merely the flash, the fleeting effect of the landscape which it is attempted to reproduce. There may indeed be considerable detail in certain portions of the picture, but the greater part is merely a color pattern. But after all such an impressionistic picture can occupy our attention for a moment only. We do indeed receive an impression more or less like that which the artist received on viewing his object, but closer study of the picture does not carry us further; there is something absent from it with which nature abounds, something that compels us, as when viewing a landscape, to keep shifting our gaze from point to point, a restlessness, a constant source of interest and fascination. In post-impressionism the attempt is being made to supply this want, to compel us namely to regard more than the fleeting impression. The closer we study such a picture, if it be successful, the more comes out of it, colors by their influence on one another become changed in hue and saturation, a curiosity develops and, subconsciously, we are compelled to continue our study, with the result that we get ever other and other effects. It is kinetic, not static, art; it is a pattern of nature designed to create visuopsychic impressions expressing an idea rather than an object, subjective rather than objective.

There is a physiological reason for this visual restlessness and before we go into the science of colors it may be well to explain what

this reason is. The innermost layer of the eye, onto which images of exterior objects are focused, is specialized to react to sensation of light, thus setting up nerve impulses which are transmitted to the brain where they are interpreted. This layer of the eye is called the retina, and it is very much more sensitive at a small spot in the center than it is over the much larger outer (peripheral) portions; so that, of the image which is focused on it, it is only that part falling on the central portion which is distinctly seen. When we regard a stretch of country, for example, it is only in one part of it that the objects are seen in any detail—namely, that part which is focused on the central portion of the retina—the remainder, since it falls on the outer portion, causing only a vague, indefinite impression. We may say, indeed, that the function of the greater part of the retina is merely to give us a general impression of the environment of the object which is being looked at, an impression, that is to say, which will enable us to judge of its relationship to other things. It tells what else there is to look at, and subconsciously we shift our gaze so that, piece by piece, the whole landscape comes to be focused on the central portion. We regard with the central portion what we know exists to be regarded on account of the duller image thrown on the rest of the retina.

Coming now to the question of color, any attempt to apply the scientific principles of color vision in making a picture must surely fail if it be not granted at the outset that it is only to a limited degree that those principles can apply. Color appreciation is as much a psychical as a physiological process, and, indeed, it is psychical not only with regard to the objective impression itself, but also with regard to the subjective, the associational mental process. Previous knowledge and training, experience, tradition, the association of color impressions with impressions previously received through other senses and stored away as memories, all play a part in determining the effect which a color or a pattern of apposed colors has upon us. But even granting all this, there are many of the physiological laws of color vision which must be adhered to before we can expect to produce these effects.

In attempting to show how these laws may be employed in art it will be necessary for us to explain briefly some of the physical and physiological observations upon which they depend. The first of these is a physical one—it is the dissociation of white light into the spectral colors by means of a prism, or better, by means of a diffraction grating.[1] The spectral colors are red, orange, yellow, green,

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[1] In the light decomposed by a prism some hues, such as those of red and yellow, occupy much less space than others, such as blue, although they do not correspondingly differ in wave length. When light is decomposed by a diffraction grating (a glass plate ruled with very fine equidistant lines) the spaces occupied by the various hues are proportional to their differences in wave lengths.

blue (indigo), and violet, the various shades of purple being entirely absent. When we look at such a spectrum we are at once struck with the fact that the colors differ from one another not only in their hue, but in their brightness or luminosity, the yellow and the immediately adjacent portions being much brighter than the others. At once, then, we recognize two physiological properties for each spectral color—hue and brightness. There is, however, another property of colors as seen in nature which is absent in the spectrum, namely, saturation. This refers to the degree of white light with which the color is mixed. It is more or less related to the artist's " value," which expresses the translation of the colors into gray.

The most characteristic of these properties of colors is their hue, and for the present we shall confine our atttention to this. To understand what the hue is due to we must remember that rays of light exist in space as vibrations of the surrounding ether and that these vibrations occur at right angles to the line of propagation of the light rays. The rate of the vibration varies according to the hue. In other words, the light rays are made up of waves which are small and close together when the vibration is rapid, as at the violet end of the spectrum, and are large and wide apart when the vibration is slow, as at the red end. When these waves strike the retina they create impressions which differ from one another, according to the wave lengths. These differences we interpret as differences in hue. When the rays of the various spectral hues are reunited before striking the retina the sensation which is created is that of white. This recombination or synthesis of the spectral hues may in general be brought about in two ways: (1) By causing them to fuse together by means of some suitable optical device (such as a second prism or reflecting mirrors) before they enter the eye; (2) by causing them to become superimposed upon one another on the retina in rapid succession, in which case the impression created by each color lasts for a sufficient length of time so that it becomes fused with those which succeed it. This result depends on the phenomenon of positive after images, which can be demonstrated by momentarily regarding some brightly illuminated object and then closing the eyes, when the image continues to be seen for some time. Rapidly succeeding images, therefore, become fused into one composite impression.

This retinal synthesis, as we may call it, is well illustrated in the impression produced by observing the spokes of a rapidly revolving wheel. For experimental purposes it is brought about by using Maxwell's machine, which consists of circular cards painted in sectors with the various colors and which are caused to revolve around their centers by means of a motor. A spinning top may also be used for this purpose. By revolving a card painted with the

seven spectral colors a sensation approaching that of white is produced;[1] by choosing various proportions of the spectral colors this white becomes tinted with all possible intermediate hues.

From these facts we might imagine that the retina contains a special kind of sensory component for each of the seven spectral hues, that equal stimulation of all produces the sensation of white, and that varying degrees of stimulation of certain of them, that of the hues which are intermediate between those of the spectrum.

Such an hypothesis could not, however, be of much practical value in explaining the color phenomena with which we have to deal in daily life. It had to be simplified. This was done by Thomas Young and Helmholtz, who discovered that three of the spectral hues, such as red, green, and violet, or certain other triads, are sufficient, when mixed on the retina, to produce the same sensations as those which are produced by the seven spectral hues. These are known as primary colors; when equal quantities of each are used a sensation of white (or gray) results; when only red and green, the sensation is yellow; when green and violet, it is blue; and when violet and red, it is purple. Not only this, but the various intermediate hues can readily be obtained by altering the proportions of the primaries; thus to produce
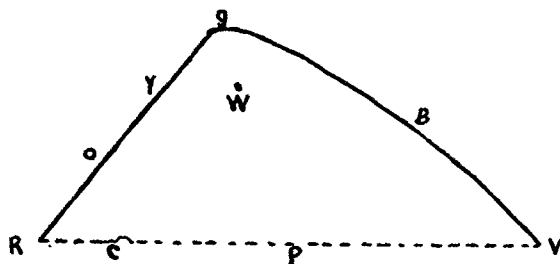
FIG. 1.—COLOR TRIANGLE.

orange, a disk containing a larger proportion of red and a smaller proportion of green is used, and so on.

To represent these fundamental facts and hold them in mind the so-called color triangle has been constructed (fig. 1). At the angles of this triangle are placed the primary hues, the other spectral hues being distributed along its two sides at distances which are proportional to their wave lengths and the purples along its base, which, since these hues are absent from the spectrum, is represented by a broken line.

But white light can be produced in still another way, namely, by retinal synthesis of certain pairs of hues which on this account are called complementary. Thus red and greenish-blue, yellow and blue, orange and blue-violet are complementary. We may express this all-important fact by stating that for every spectral hue there is another which when mixed with it on the retina in approximately equal quan-

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[1] It would be pure white were it possible to obtain artificial pigments that reflected none other than their own characteristic hues.

tities produces the sensation of white. When other than equal proportions of complementary hues are chosen, colors are produced which are of hues intermediate between those of the complementaries and which are mixed with varying degrees of white. They are incompletely saturated colors. These facts may be satisfactorily represented by finding a point, called W, inside the color triangle, so that any straight line passing through it will on striking the sides of the triangle join two hues which produce white. This method of finding the complementaries necessarily implies that they must be separated from one another by a considerable distance on the spectrum. For representing these facts a circle instead of a triangle may be employed, and for practical purposes, in the use of colors in painting, such a circle has been found more useful than the triangle. Before we proceed to explain its use, however, it may be well to indicate some of the applications which can be made in art of the facts we have already learned.

It is in pointilism that this application is most evident. In this method the pigments are laid down in minute areas or spots or lines so that when the picture is viewed from a certain distance, the different hues act on the same nerve endings of the retina and therefore produce the same effect as if they had been superimposed, as by the use of Maxwell's disks. Thus, if a white surface be dotted over with red, green, and violet, or any other primary colors, or with red and greenish-blue, or any other complementary colors, the surface at a certain distance will appear grayish white. If, in any of the combinations, one hue be in preponderance of the others the gray will become correspondingly tinted, so that a complete picture may be built up of areas which on close inspection are a mosaic of pure colors, but appear at a distance as tinted grays.

The impressionists, Monet, Segantini, etc., appear to have laid as the basis of their picture a gray at the brightness (or value) which they desired each portion of it to assume. On these surfaces they then applied color more or less pointilistically. The neo-impressionists, such as Seurat and Segniac, on the other hand, went a step further in that the saturation was made to depend entirely on the synthetic principle. They laid on their pigments strictly in dots on a surface which was as nearly pure white as possible. Some of these neo-impressionists had, however, already begun to apply certain of the principles of color apposition in masses which we shall study later. To build up a picture pointilistically must obviously greatly increase the technical difficulties of the artist, especially with regard to outline and form; his freedom of expression is also seriously curtailed. It becomes necessary therefore that very great advantages should be the outcome of such labor. Among the advantages are the sense of atmosphere, the vibrating, scintillating quality of the color areas and the

very satisfactory transitions at the edges between them, all of which are qualities that can be rendered in no way so satisfactorily as by pointilism.

There can be little doubt that a great part of the peculiar impression produced by pointilism depends upon the slight movements which the eyeballs are constantly undergoing, even during our most intent fixation. This of course produces a certain amount of overlapping of the colors on the retina just as when they are superimposed by means of Maxwell's machine. In the same way vibrations of the eyelids by moving the eyelashes across the palpebral cleft assist in the synthesis, this being made evident by half closing the eyes, a method often used in studying pictures.

The success with which the desired impression can be created in a pointilistic picture often depends upon the purity of the colored dots, its vibrating quality being at the same time much enhanced by leaving a narrow margin of white around each dot. When this is successfully done there comes into play another physiological process known as flicker, which can be experimentally produced by rotating disks with black and white sectors at a speed which is just insufficient to cause a uniform gray. The resulting flicker possesses a glittering quality which makes it appear of distinctly greater brightness than the gray which results from complete synthesis. The same thing may be seen by observing the spokes of a wheel revolving at different velocities. Instead of black and white the sectors may be composed of different hues.

In the flicker experiments the gray remains of the same degree of saturation at whatever rate the disk is revolving, provided it is revolving more quickly than is necessary to produce complete fusion, and so in pointilistic painting, when the picture is viewed beyond the distance at which fusion occurs the impression is practically that of the older painting. It must be viewed at a distance just short of that which is necessary to produce complete synthesis. The post impressionists, such as Cezanne, Matisse, etc., realizing this limitation in pointilism, have been searching after a method by which the color scheme maintains its effect on us at whatever distance the picture is viewed. The physiological principle upon which this depends is that known as contrast, and this we will now proceed to study. Being a property exhibited most strikingly in the case of complementary hues, it becomes necessary for us to have, besides the color triangle, some simple experimental methods by which the complementary hues may be determined. Such methods include the experiments of simultaneous and successive contrast, in connection with which many facts of fundamental importance in the use of pigments are brought to light.

Simultaneous contrast is illustrated by regarding a strip of gray against a colored field when the gray becomes tinted with the complementary hue. There are two simple methods for performing this experiment, one is to spin a colored disk, midway between the center and circumference of which is a circle, composed partly of black and partly of white; this synthesizes to a gray which becomes tinted with the complementary hue of the colored field. The other way is to lay a narrow strip of gray paper (cut as a zigzag) on a colored sheet and then to cover the whole with thin tissue paper; the gray will assume the complementary hue. No experiments in color vision are more striking than these, nor are there any that have more direct application in the use of colors in picture painting; thus, a gray wall viewed against a sunlit background of green is no gray, but like the piece of paper in our experiment it becomes tinted of a purplish hue. Similarly, a shadow cast on yellow sand is blue, and one thrown on the skin when this is otherwise in strong light often acquires a striking quality of green.

The phenomenon of successive contrast is elicited by steadily regarding a patch of a certain color for some time and then either closing the eyes, or better still, directing the gaze to a neutral surface, such as a gray untinted wall. A vivid color impression of the same shape as that of the colored patch previously looked at will be seen in both cases, but exhibiting a hue which is complementary to that of the patch.

In the experiments above described the complementary color is demonstrated by the use of a gray surface. It is evident, however, that, if we cause it to be projected against a background which itself possesses a certain hue, the two hues (the complementary and that of the regarded surface) will become blended and will have the same effect as if they had been spun on a Maxwell's disk. For example, suppose we regard for some time a blue surface and then direct the gaze to one of red, the impression will be that of orange, because the complementary of blue, being yellow, fuses with red and produces orange.

Having determined the complementaries by means of these contrast methods we may confirm our results by color synthesis; thus supposing we have determined by the contrast methods that the complementary for a certain yellow is a certain blue, we may proceed to ascertain whether this is strictly the case by preparing disks composed of these two hues and rotating them on Maxwell's machine. If the hues are complementary the greatest possible degree of whiteness will be produced.

Successive contrast finds only a limited application in art, although it is of course conceivable that the intensive fixation of one colored area in a painting or a design might, by successive contrast, greatly

modify the colored impression created by shifting the eyes to another part. It is improbable, however, that any artist has laid on his pigments with this object in view. Nevertheless, successive contrast may assist us greatly in the actual determination of the complementary hue. Thus, to take again our example of the gray wall against the green background, we may exaggerate the effect of the green on the gray by regarding the green for some time and then shifting the gaze to the wall, when its purplish hue will be found to be much intensified.

Simultaneous contrast, on the other hand, is of paramount importance in art; indeed, it is as important in the final impression produced by a painting or a design as any other quality which this may possess. This importance depends on the fact that when two colored surfaces are placed in apposition each becomes changed as if it were mixed to a certain extent with the complementary hue of the other; or if a gray or a tint of low saturation (see p. 733) is apposed against a saturated color field it will assume a complementary hue of greater or less saturation, according to the relative area of brightness of the apposing areas. By applying these principles in picture painting unsaturated hues may be caused to assume much greater degrees of saturation, while, if the apposition be false, hues in themselves of almost complete saturation may become dull and subdued.

To the artist it comes to be of the highest importance that he possess some easily remembered scheme by which he can predict these contrast effects. The color triangle may be thus employed, but a simpler, though perhaps less scientific device, for the same purpose is the chromatic circle of Rood (fig. 2). To construct such a circle we must know the wave lengths of the various colors which we desire to contrast.[1] The differences in wave lengths are then calculated so as to correspond to angular differences, these angles being formed by the radii of the circle. As in the color triangle, opposite radii will join complementary colors and the center will represent white light; i. e., the nearer the center the less will be the saturation of the color.

If one such circle, drawn on transparent paper, be superimposed on another, the effect which is produced by contrasting two colors can be readily ascertained. Thus, suppose we desire to determine the influence which red has when contrasted with the other colors. Having accurately superimposed the two circles we move the transparent one so that the point on it which corresponds to red is displaced along the line joining red and its complimentary, blue-green. The colors on the upper circle will now stand in positions on the lower corresponding to the changes in hue and saturation which they would have suffered by contrast with red. Thus orange will stand nearer the

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[1] This can be done by comparing the colors with those of a highly magnified spectrum of white light alongside of which is a scale of wave lengths.

center and somewhat nearer yellow, whereas green-blue will merely be removed farther from the center, which means that orange will become less saturated and yellower, whereas green-blue will increase in saturation but be unaltered in hue.

In general we may say that the effect produced by contrasting two colors is to move them farther apart on the chromatic circle, thus causing mainly a change in hue in the case of colors that stand near one another, but making a change in saturation in those which are far apart.

In order that the contrast effects may be taken full advantage of certain conditions must be fulfilled. The most important of these are as follows: (1) The complementary tint which gray assumes is most vivid when it is somewhat darker (i. e., of less brightness, see p. 734) than the hue against which it is apposed, in the case of the warm colors (the reds, oranges, and yellows), and when it is lighter in the case of the cold colors (the greens and blues). The dividing line between the warm and cold colors may be taken as that joining the complementaries, yellow-green and violet. (2) When a color of low saturation (i. e., nearly a gray) is apposed to one of high saturation and of complementary hue the former will become more saturated, and, conversely, if two colors which are identical in hue but of unequal saturation be apposed the paler one may appear gray. When they are not complementary the hue which undergoes the greater change is that which is the paler. (3) The greatest effects are produced when the color field whose hue it is desired to alter is much smaller in extent than that of its complementary and when it is completely surrounded by the latter. By placing a thick black line between the areas the complementary effects may be suppressed. Thus the complementary hue which a piece of gray paper placed on a colored field assumes when it is viewed through tissue paper becomes much less evident if a thick black line be drawn on the tissue paper at the edge of the gray. When the color areas are large, it is at the edge only that the complementary influence is noticeable. On

FIG. 2.—ROOD'S CHROMATIC CIRCLES AS USED TO SHOW THE INFLUENCE OF ONE COLOR ON THE OTHERS.

the other hand, when a colored area is very small it undergoes no complementary change, but merely blends with the neighboring color. (4) To obtain full advantage of color apposition the colored patterns should be very simple and of similar texture and their surfaces should be broken up by detail to the least possible degree. (5) The most marked complementary effects are obtained when the opposing hues are of equal brightness.

When we attempt to employ the chromatic circle for another purpose, namely, for determining what will be pleasing and what displeasing color combinations, we find that its use is somewhat limited. This is because a psychological influence enters into our judgment in such cases. In general, however, it may be taken as a working hypothesis that good combinations are always more than 80–90° apart on the circle; that is, they should be separated from one another by about one-quarter of the circumference. Even complimentaries may form displeasing combinations (i. e., certain reds and greens), in which case, as Rood has pointed out, the hues are usually far removed from the line which separates those that are cold and warm. When we are compelled to appose hues having a hurtful influence on one another, the unpleasing impression which they create may be lessened by certain expedients, such as by assigning one of the hues to a much smaller field, or by decreasing the saturation of one of them. or by adding a third hue whose position on the chromatic circle is as far as possible removed from the others; thus the disagreeable effect of a yellowish-green and yellow is much improved by the addition of some violet, etc.

So far, for the sake of simplicity, we have regarded but one quality of a color, its hue, although in doing this it has been impossible entirely to neglect the closely related qualities of brightness and saturation. These we shall now proceed to consider.

Brightness is most marked, under ordinary conditions of illumination, around the yellow portions of the spectrum. It is a property which is exhibited in marked degree by different grays. Indeed, it is measured by finding a gray which appears of equal brightness to that of a given color. Such measurements may be made with considerable accuracy by finding a gray background against which the color becomes indistinguishable when viewed by the very outermost portions of the retina which are color blind; that is, which see no hue in a color but only a grayness, the degree of which is proportional to the brightness of the color.[1] To make such comparisons, the person must regard a dot in the center of a plain black surface and must then

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[1] The power to judge hue depends on the presence in the retina of peculiar nerve endings called cones. These are absent from the peripheral portions and only gradually make their appearance toward the center. There is, therefore, a region between the periphery and the center of the retina which is partly color blind, blue and yellow being perceptible, but red and green still appearing as gray.

gradually move a small piece of colored or of gray paper, mounted on a suitable handle, from the periphery toward the center of the surface. At a certain position the colored paper will be seen as gray, because the rays of light from it are striking the color-blind areas of the retina. Various grays are used until one is found which matches exactly with that created by the colored paper. A still simpler method consists in rotating the color on a Maxwell disk along with a synthetic gray. In this case judgment of equality may, however, be somewhat confused on account of the gray assuming the complementary hue.

Brightness plays a most important part in the phenomenon of contrast, for not only is the simultaneous contrast of hues obtained most strikingly when these are of equal brightness, but we constantly experience brightness contrasting itself. Thus pieces of the same gray paper placed on gray backgrounds of varying degrees of brightness do not look at all alike. It is particularly at the border between the two grays that contrast brightness is most evident. This subserves the function of creating a sharp border between the grays, and it can be demonstrated by causing strips of different gray papers to overlap one another like the tiles of a roof or, still more strikingly, by rotating a disc on which when spun appear three circles of different grays, each synthesized from black and white. In both experiments the grays, though really perfectly uniform, will appear as if shaded from their edges.

Since we measure brightness in terms of grayness, and since it is most marked at the yellow portion of the spectrum, it follows that if we desire, for successful contrast effects in picture painting, to appose yellows with blues or deep reds, we must employ some artificial means either to increase the brightness of the blues or reds or to decrease that of the yellows. This can be done by mixing the pigments with white (or black), that is to say, we may alter what the artist speaks of as the value of the color but which in so far as white is used for producing the alteration is more correctly called the saturation.

It may indeed be said that the object sought in mixing pigments with white (i. e., changing their saturation) is to give the impression that their properties of brightness have been altered.[1] When it is desired to raise the brightness of a given color, we can succeed only to a limited degree by using more pigment; to obtain it further, we must, as already explained, employ the property of simultaneous contrast. These methods used by the artist to alter the brightness of his colors are, however, liable to have a dulling effect on the whole composition unless they are used with great care and judgment.

[1] Brightness must be distinguished from color intensity, which is purely a physical property and depends upon the amplitude of the wave lengths.

When he is compelled to lower the saturation of one color he must be careful to apply those neighboring on it in such a manner as to give the impression that the whole of that portion of the picture is of the same brightness. This he may do, either by making his pigments of similar saturation of by assorting the size of the colored areas, so that they appear by contrast to be of similar saturation.

It is a well-known fact that our judgment of the relative brightness of colors, and to a certain extent of their hues, becomes altered when the conditions of illumination are changed. A picture viewed in broad daylight may create a very different impression from that which it produces in dull illumination. For example, its hues may be dull and muddy under the conditions of illumination that are ordinarily present in a dwelling, or even in a gallery, whereas when viewed in broad daylight it may sparkle with brilliancy, or there may be very little change in the actual hues, but the portions of the picture which appeared to be of greatest brightness in broad daylight may in dull light actually shift to some other part. These changes are due to what is known as adaptation of the retina. The most striking illustration of this is furnished by observing the colors of a flower border after sundown. Let us suppose that the border contains geraniums (scarlet), lobelia (blue), and coreopsis (orange). As darkness approaches it will be noticed that the red geraniums become duller and duller until at last they turn black; that the orange coreopsis also becomes more neutral, but that the blue lobelia maintains the same color qualities as it possessed in daylight. The most remarkable change of all occurs, however, not in the hues, but in the relative brightnes of the colors, for it will be noticed that the sensation of greatest brightness has gradually shifted from the reds and yellows to the blues and greens, so that the foliage and the lobelia may actually come to appear brighter than the coreopsis and the geraniums. It is needless to point out how important an appreciation of these adaptations must be to the artist; how careful he must be to paint his picture in the degree of illumination in which he expects it to be viewed. The physiological explanation of this adaptation is that the outer portions of the retina assume a much greater degree of sensitiveness in dull light, indeed, they come to be more sensitive than the central portion itself. This curious change explains why without directly looking at it we may be conscious of the presence of a small light in the darkness—a star for example—which, however, disappears when we direct our gaze to it. The ability of the thus sensitized outer portions of the retina to judge colors differs from that of the central portion.

When we come to apply many of the principles of chromatics in art, we are met with difficulties which at first sight may appear to be insurmountable. In most instances, however, this is by no means

the case, and we shall now endeavor to show how certain of these difficulties can be explained. First of all, with regard to the mixing of pigments as compared with the mixing of colored lights, of course the two processes yield very different results: for example, mixing yellow and blue lights, as we have seen, produces almost pure white, whereas mixing these colors as pigments, as every artist knows, produces green. The entire want of similarity in the results which follow the mixing of colors by the two methods has had the effect of making some artists conclude that the laws of chromatics are useless as guides in the practical use of pigments. But this is wrong, the apparent difference being really due to a very simple cause, namely, to the fact that by mixing pigment we substract the color rays from entering the eye, whereas we add such rays when we mix colored lights. To make this clear let us return to our example of blue and yellow. When we use these as pigments, we must remember that the pigment particles have a certain degree of transparency so that light partly penetrates them, certain rays being then reflected and certain absorbed according to the hue. A blue pigment, for example, absorbs all constituent rays of white light except the blue and the hues which border on blue in the spectrum, it being impossible to procure pigments which are so pure that they do not let some other hues besides their own characteristic one pass through them. Similarly, yellow absorbs all the spectral rays save the yellow, the orange, and the green. Adding these two pigments together, we get every spectral ray absorbed except green, a certain amount of which both pigments have allowed to pass. In a similar way we can explain why blue and red give purple and why a mixture of all the spectral colors as pigments produces a dark gray of uncertain hue.

The above applies to a matt surface; when there is any trace of glaze, there comes into play another factor which we must now consider, namely, surface reflection of some white light which has not penetrated the pigment particles at all, and which therefore causes the color to be more or less unsaturated. It is by diminishing surface reflection of white light that the colors of a picture may be raised in saturation by subjecting it to alcohol vapor, which softens the medium and removes surface cracks. Reflection of white light also takes place at the surface of the pigment particles themselves, and is greatly diminished when these are extremely small, hence the importance in the manufacture of pigments of thorough grinding. It is further minimized by suspending the pigments in oil, because this causes the light before it strikes the surface of the pigment particles to pass through a medium which is of approximately the same density as that of the particles themselves. This reduces the reflection, because the greater the difference of density between two media the greater the reflection of light at the interface between them.

The quickly vibrating (blue) rays of the spectrum tend to be re-flected more readily than the slowly vibrating (red) rays, hence we often find that a substance is bluish by reflected light, whereas it is reddish when the light passes through it. It is, indeed, for this rea-son that during the day the sky looks blue, the light being reflected from the fine particles of dust and moisture which are constantly suspended in it, whereas after the sun has set it is red because the slanting rays come to be transmitted through these particles.

Artificial illumination alters the hues of pictures mainly because of mixture of colored lights; that is to say, of the hue of the light re-flected from the surface of the picture and of the hue due to the par-ticular pigments employed. Thus, if we regard a picture in yellow light (gas, carbon filament, etc.), the pale blues may appear white (mixing of complementary colors), the deeper blues assume a green-ish hue; and the reds turn to orange.

In the colors which we see in nature influences of a similar kind are constantly at play, for every object, besides being illuminated by the prevailing light, has thrown on to it colors which are reflected from near-by objects. In analyzing these influences there are, as Rood has pointed out, at least three factors that must be borne in mind. These are (1) the natural or "local color" of the object, the cause for which we have already explained; (2) the colored light which is reflected unaltered from its surface, just as we have seen white light to be; (3) the portion of this colored light which is not entirely reflected but which penetrates the surface and is then re-flected. Let us suppose that we are regarding a red wall of glazed brick at the edge of a grass lawn: the local brick red of the wall will be materially altered by surface reflection not only of the white light but also of blue-green which, being approximately its comple-mentary, tends to lower its saturation and pull it toward neutrality; at the same time, the green rays which have penetrated will on re-flection assume a yellowish orange hue. The total effect is therefore that the red is somewhat removed toward neutrality and at the same time made to assume an orange hue. But it is by no means always possible to analyze these color effects, so that we must depend rather on the accuracy of the impression which we receive, at the same time bearing in mind that even objects with which we usually associate the most positive of hues may under certain conditions become en-tirely altered in this regard. In their use of colors, the post-impres-sionists are most careful to allow for these influences, although they may employ hues to produce them which at first sight appear to be entirely out of place.

Finally, we must say a few words about the relative refracta-bility of different colors; that is to say, the ease with which the

different spectral hues are brought to a focus on the retina. The rays of slow vibration, as at the red end of the spectrum, are less readily focused than those which vibrate quickly, as at the violet end. Consequently, when red rays are in focus, violet rays are overfocused and vice versa. The application of these principles in art depends on the fact that our judgment of distance is partly associated with the amount of effort which we must make in order to accommodate our vision. At rest the optical apparatus of the eye is accommodated for distant objects so that when these come nearer than a certain point an effort is required to make the focusing stronger. From the amount of this effort we judge in part of the distance of the object. Now, it takes more effort to focus red than green or blue rays so that we always tend to locate a red object as being nearer than one that is blue or green. These facts can be very beautifully demonstrated by looking at red and green lamps placed side by side; the green light appears to be behind the red. And in picture painting the same principles can be applied, and seem to be so in many of the post-impressionists' paintings; objects are brought forward by being colored in the reds and they are pushed back by the use of blues and violets.

These facts bring us to a discussion of the influence of the blue-violet line which so many post-impressionists are using to outline objects to which they desire, without shading, to give the impression of rotundity, or more correctly, of projection. The effect of such a line is perhaps best demonstrated in still-life studies where its existence at the edges of, say, a vase, will, when the picture is viewed at such a distance that the line just disappears. cause the vase not only to stand forward from its background but also make it appear rotund, as if shaded toward the edges. The line is sometimes used in landscape pictures with the object of holding the pattern together. These effects are most marked when the object is painted in hues that are considerably removed from blue on the chromatic circle, or are of much less saturation (more removed toward neutrality). Similar effects can sometimes be obtained by the use of a black line, but none of the flaring hues can be successfully employed for making it. It is difficult to explain the action of these outlines: indeed, it is almost certain that several factors play a rôle in producing the illusion which they create. When the line is a blue one and the prevailing hue of the color field which it borders tends toward yellow a synthetic gray will result at a certain distance, thus creating the impression that some space exists between the object and its surroundings. When a black line separates two colored areas there occurs a certain amount of irradiation on to it of the neighboring hues, which therefore undergo a more or less sudden lowering of intensity at its edges, which become more and more pronounced toward the middle of the line until the hues finally meet and partly overlap, thus producing a

certain amount of synthetic gray. This phenomenon of irradiation is well illustrated by comparing two squares of equal size, one being black on a white field and the other white on a black field; the white square looks distinctly larger than the black one. The reason is that the stimulus produced by white, mainly because of imperfect focusing, spreads on the retina somewhat beyond the margin of its image.

In this account we have not essayed to explain all of the peculiar effects which are produced by some of the most modern creations of the so-called post-impressionists. We have merely indicated some of the physiological truths of color vision upon which certain of their color illusions depend. To go further would require consideration of many optical illusions for which at present there exists no satisfactory explanation. These are not illusions of color but illusions of line; indeed, many of the latest post-impressionistic pictures are produced almost entirely in black and white, and the peculiar emotions which they arouse depend on metaphysical processes whose explanation we can not undertake to expound. Their aim is " to create an illusion of the fact " rather than the fact itself; to write " a visual music which shall in itself arouse the emotions."

FUNDAMENTALS OF HOUSING REFORM.[1]

By Dr. JAMES FORD,
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A housing problem may be said to exist wherever any portion of a population dwells under conditions dangerous to health, safety, or morality. The problem is present to some degree in every American city. It is usually occasioned primarily by the lack of guidance of urban growth, by poor planning of buildings, faulty construction, and defective sanitation; it is aggravated by the greed of some landlords, the carelessness of some tenants, and ignorance of the laws of hygiene on the part of both. The result of bad housing is ill health, both physical and moral, and thereby industrial inefficiency, unemployment, and a long chain of preventable social maladies, which are very costly to the community, and which place a heavy handicap upon individual and social achievement.

HOUSING AND PUBLIC HEALTH.

Man's dwelling exerts a marked influence upon his life and character. From one-third to one-half of his time—and much more than half of the time of women and children—is spent in the home. Bad housing conditions affect health insidiously by slowly undermining the vitality and thus rendering the individual susceptible to disease. But bad housing conditions also constitute an environment favorable to the life of the germs of a number of diseases. For example, the bacillus of pulmonary tuberculosis can live for weeks and even months in a dark, damp, ill-ventilated and ill-kept environment—in other words, in basement dwellings, in dark halls and dark chambers. The germ of typhoid fever may not only be conveyed through the water or milk supply of a city, but is stated also to be carried by flies and vermin from the filth in which it was deposited to the food of urban households.

Thus a city with an insanitary water supply, or with manure pits and garbage pails uncovered in which the fly may breed and privies in which the bacillus may be picked up, is an environment favorable

to the spread of typhoid fever. The tenement house with its halls, stairs, and water closets shared by many families becomes a sort of clearing-house of the contagious diseases—scarlet fever, measles, etc. The common water-closet may be the source of spread of venereal disease. The indiscriminate overcrowding of sleeping rooms by both sexes may result in the spread of the same diseases and also in an undermining of the health of adolescents and adults through neurasthenia and other diseases which over-stimulation of sexual instinct and its unsatisfactory fulfillment may occasion.

HOUSING AND PUBLIC SAFETY.

The safety of an urban population is in many ways affected by housing conditions. The overcrowding of lots with buildings erected of combustible material creates a serious conflagration risk, especially where buildings are of frame exterior or are used both as stores and dwellings, as is common in our large American cities. Fire escapes reduce the danger to tenants from fire, but improperly constructed fire escapes constitute a new risk from accident. The presence of stores, bakeries, and work shops in nonfireproof tenement houses; the storage of combustible materials, such as rags, paints, etc.; the encumbrance of fire escapes; the proximity of railroads, and the manufacture of explosives—all affect in varying degree the safety of the tenant.

HOUSING AND MORALITY.

Intimately dependent upon the housing conditions is the morality of the population. The crowding of rooms with three or more members of a family, children of both sexes sleeping together or with parents, and the presence of lodgers within the tenement make impossible the maintenance of high standards of personal decency. Premature knowledge of sex function by the children is the inevitable result of overcrowding, and often morbid stimulation of sex instincts, sex perversion and vice originate in room congestion. Yet indiscriminate crowding of sleeping rooms prevails very widely within the immigrant population groups of our cities. The dark halls and common toilets add to the menace for the growing children of the tenements; and frequently the presence of commercialized vice within residence quarters familiarizes the child with the worst element of our civilization before the child's mind is far enough developed to resist the superficial allurement.

HOUSING AND EFFICIENCY.

A general reduction of vitality, or disease of any sort acquired through residence under conditions above described, results necessarily in reduction of industrial efficiency. Disease causes absence from work, which means reduced earnings, increased expenses, and

perhaps also a long period of unemployment before new work is found. In extreme examples a state of mind which has been termed "slum disease" is apparent, in which individuals have become chronically indifferent or careless because they have found themselves unable to cope effectively with an always depressing environment. The serious effect of this attitude of mind upon industrial output is obvious.

HOUSING AND SOCIAL WELFARE.

It is impossible to create a high civilization in a democracy where a large portion of the population must exert its entire life in struggling against destructive environmental conditions. The body is the tool of both mind and soul. A healthy body is a first requisite of the largest moral life. An individual can contribute little to the promotion of general well-being until rid of the weakness or pain which ill health causes. The essential prerequisite of efficient democracy is a healthful home life, with elimination of all the destructive elements now present in our slums and with the presence of the constructive elements—sanitation, safety, ventilation, sunlight, space, privacy, and beauty.

HOUSING LEGISLATION.

Public action, to render the existing slum less dangerous to physical and moral health, begins in "health acts," the provision of public water supply, public sewage systems, and the regular collection of refuse. Modern cities or States usually go further and frame health laws, governing the minimum sanitary conditions of existing dwellings. In America the inspection under these laws ordinarily falls as an additional task to existing health or police departments. Building codes, enforced by a local department of buildings, generally set minimum standards for the construction of new buildings. There is a definite modern tendency to fuse requirements covering new and old tenement houses in tenement house acts or housing acts passed by State legislatures. Such acts may apply to specified cities, to cities of specified classes, or to an entire State, and may be either compulsory or permissive. The requirements should cover height of new or altered buildings, size of yards, courts, rooms, the lighting of rooms and halls, fireproofing, etc., and should establish standards of sanitation and upkeep which would make it impossible for any person to build or occupy a tenement which is demonstrably dangerous to health, safety, or morality. Administration under such acts should be definitely provided for, with ample penalties and ample funds for continuous and careful inspection, and for all office work involved under the act. The details of such laws are suggested by the experience of New York City, New Jersey State, Columbus, and by Mr. Lawrence Veiller's recent book "A Model Housing Law."

THE CITY PLAN AND THE HOUSING PROBLEM.

The planning of cities involves the adjustment of the physical resources of the city to meet the needs of its population, present and future. The proper planning of cities may be made to improve housing conditions in a variety of ways. The functions of city planning may be considered conveniently under two captions. First, the remodeling of the old city, and second, the determination of the mode of development of new sections. Of these the first program is largely remedial in character, while the second is fundamentally preventive.

From the housing point of view the remodeling of portions of the city already built may not have a marked effect upon the dwelling conditions of the population in quarters so treated. In any district in which streets are widened or trees or grass strips are placed, impetus for the remodeling of old buildings is likely to be purely superficial. A new brick face may be placed on an old insanitary building. The dark room may remain. Still under such conditions the occupants profit by an increase of light and air from the widened street, by purification of air where trees are placed and by the increased beauty of their outlook.

THE INSANITARY AREA.

City planning within the heart of a built-up city may also involve schemes for dealing in a large way with districts in which the houses are highly insanitary and are beyond repair, positively unsafe, and dangerous to health and morality. There are many ways in which a district of this sort can be treated. First, it may be neglected by health and tenement departments that are overworked and unable to deal with a problem so large and apparently hopeless. In the second place an attempt might be made to repair the district, either at the cost of the city or by the city at the cost of the owners (the Birmingham method), or the owners might be ordered to make the necessary repairs at their own expense. Special powers would be necessary if improvements on private estates are to be made by the municipality at public expense. The third program would undoubtedly result in a patchwork reform. No one of these programs is adequate to deal with such districts; they are merely palliative and might reduce but would not destroy the unhealthfulness of such a district.

Another possibility would be the complete destruction of the entire area by the city. This might be done with the intention of replacing the area with a park—as was done by New York City, for example, in the notorious Mulberry Bend—or the area could be rebuilt by the city with municipal dwellings or other buildings. The cost of the first half of this latter program renders it undesirable if there is a cheaper alternative which is equally effective. As for the latter, municipal

rebuilding of insanitary areas, even in London and Liverpool, where municipal housing is an accepted form of municipal business, has never proved a paying undertaking, chiefly for the following reasons:

1. The original cost of the land and of the destruction of the insanitary houses is either prohibitive or places a too heavy initial charge upon the undertaking.

2. It has been found impossible to build municipal tenements on the same area to house healthfully as many persons as were dishoused by the slum-clearance scheme.

3. The original dishoused population tends to crowd with other families in small tenements while the area is being rebuilt, and does not return to the new buildings when completed, largely because the rents are inevitably higher than they were for the original accommodation.

4. It becomes profitable for a low class of speculators to buy insanitary property and hold it unrepaired in the hope that the Government will purchase it for a slum-clearance scheme of this sort, paying them, as is usually the case, more for the land and buildings than they are really worth.

Even if these arguments were not operative in American cities, municipal housing would for the present at least be undesirable, both because it is unnecessary (private capital, properly encouraged, can be relied upon to provide the necessary accommodations) and also because in our American cities we can not guarantee the continued employment of expert men to operate a municipal housing department. Municipal housing will not pay where long tenure of office can not be guaranteed to efficient administrators, or where politics and slender appropriations can ruin the work of competent administrators.

TAXATION OF LAND VALUES.

Another possible way of dealing with such an area deserves very serious and extensive consideration, and that is the use of a system of heavy taxation of land values or of the unearned increment. As these measures involve many other considerations besides those of housing, these other bearings of the subject should, of course, be studied with utmost care before the adoption of the scheme. As a fiscal measure, however, the taxation of the unearned increment from land values is, without doubt, a peculiarly just form of taxation and is calculated to bring large annual sums into the city treasury. There is no question that the community is chiefly responsible for increases in land values. It is just, therefore, for the community to appropriate such increases in value, especially if it can do so without placing any hardship upon industry. The only serious difficulties arise in determining a practical method of appropriation and assessment.

The diverse schemes of New Zealand, Germany, England, and western Canada should, therefore, be studied, and the desirability of using one of these methods should be considered.

The application of a heavy tax on land values (Vancouver method) in the district under consideration [a district in which the value of the land far exceeds the value of improvements upon the land] would have a marked effect upon housing conditions, and would be the cheapest way (assuming that a just method of appropriation was found and employed) in which the city could deal with this district. If the tax were taken off the buildings within such a district and the entire tax was levied upon land, the owners of this property would find it unprofitable to hold their land in its present wretched state. If the entire tax of the city were levied upon land values, the owners of all property that is improved would find their taxes reduced, but the holders of vacant land or of land uneconomically developed would find their taxes increased, and would be confronted with the necessity of building or of selling to some individual who would be willing to build.

IMPORTANCE OF RADIAL STREETS.

The housing conditions of a city are affected materially by the street plan. If suburbs are not accessible directly and cheaply from the centers of industry and commerce, population will tend to crowd in tenements near the heart of the city. Suburbs are rendered especially accessible by means of broad, direct, radial streets, suggestively termed the arteries of the city. Many American cities are built upon a gridiron plan of streets, which renders certain suburbs peculiarly remote because accessible only by following two legs of a triangle instead of following directly upon the hypotenuse.

TENEMENT VERSUS COTTAGE.

The type of city plan which should be secured for your city must depend upon our answer to the question, What is the most desirable dwelling place, the tenement or the cottage? In the cities of the Northeastern States we have become accustomed to the tenement house and do not ordinarily question its social utility. There is scarcely a city in the country that is attempting in any well-considered way to eliminate the tenement house, yet there can be no question but that it is an undesirable place of residence for families with children. Even for the childless family, the most expensive apartment house as well as the cheapest tenement may constitute an undesirable environment, because of the facility with which disease may spread from one apartment to its neighbor through the common hall and through the mediation of vermin which pass easily from one suite to another.

Where people live in apartments there is also concentration of population and hence much traffic in the neighboring streets, which keeps the air full of dust and noise and thus renders apartment living undesirable. The sounds from neighboring apartments frequently make rest and quiet impossible. True privacy and solitude, though very important to the moral growth of the individual, are difficult to obtain.

For the family with children the apartment is still less desirable. It becomes impossible for the mother of a family to choose the associates for her children, to prevent her child from coming in contact with children or adults of unwholesome character who may reside within the same building. The tenement mother can not supervise the outdoor play of her child. In general the atmosphere of the tenement or apartment house is one destined to create a race of adults that are unhealthful, puny, and socially highly artificialized.

In the cottage, however, it is possible to obtain all necessary privacy for true home life and personal development. The reduced dust of suburban communities and the larger penetration of sunlight make cottage homes healthier living places for infants and growing children. The mother of the family, while at work in her kitchen, can supervise the play and the associates of her child in the garden. The adults of the family, if so inclined, can profit in health at least—and sometimes in economy—by cultivating a garden outside of working hours. The children gain the advantage and education that come from daily contact with the things of nature, especially through the garden. It is probable, therefore, that, at least for families with children, the suburban home is preferable to the tenement.

It is, however, impracticable to house the population of large cities in cottage homes unless such homes can be constructed to rent for a price (including both the cost of land and of the daily transit to and from work) no higher than the same family would pay for an equal number of rooms within the city tenement. Furthermore, families working within the city will not live in the suburbs if a too large proportion of their working day is consumed in transit to and from such residence. If any working member of such family is employed for 10 or 12 hours a day in the heart of the city, the residence should not ordinarily be placed more than one-half hour's ride from the place of business. To secure cottage homes, therefore, for the working classes of our cities, it is essential to have rapid and cheap transit, serving satisfactorily all of the possible outlying residential section. It is equally necessary to have an abundance of cheap land and to make possible the cheap construction of cottage homes.

One means of encouraging cottage construction is to discourage tenement building. If, for example, we require tenement houses

over four stories high to be constructed fireproof throughout, as do Philadelphia, Pittsburgh, Scranton, St. Paul, and St. Louis—and require the three or four story tenements to have brick exterior, stairs, halls, and fire towers—investors in house property will construct houses less than three stories in height because they will be comparatively cheaper in cost per unit of construction.   Massachusetts towns, which have adopted the permissive tenement-house act for towns—Belmont, Arlington, Winthrop, etc.—have eliminated the three-story tenement house for the future by requiring that every tenement house three stories in height shall be fireproof throughout.   The cities above mentioned are all of them peculiarly free from high tenement houses.

THE ZONE SYSTEM.

The measures above indicated would tend to eliminate from your city all new construction of high tenement houses except for apartment houses of the well-to-do classes.   They would not, however, absolutely prevent any man from constructing such apartment houses on any lot in the city or suburb which he might chance to own.   It would still be possible for a man to place a high apartment house in the midst of a block of private residences, shutting out light from his neighbors' homes, marring the beauty of their outlook with the ugly back of his building, and bringing into that street a class of population of different tastes and perhaps of a type from which neighboring parents would wish to protect their children.   The city of Calgary, in Alberta, attempts to meet this difficulty by providing in its local building code that no owner shall build an apartment house within any city block unless two-thirds of the other owners in the block give their assent.   This provision is, however, inequitable, in that it does not give all the persons who are interested in the erection of such apartment house an opportunity to vote.   The owner of the property across the street would be equally affected by the building of such apartment house; so, also, in less degree, would the passerby whose outlook may be marred by its erection.

To protect a community from the intrusion of undesirable building types, it might be desirable here, as in German cities, to establish a zone system of building.   The essential feature of the zone system is that a city is divided into districts in which building types are permanently fixed.   In the heart of the city the highest buildings may be erected (six stories, in the case of Vienna) ; in the next district, near the center of the city, buildings may be erected one story less high and perhaps covering a smaller proportion of their lot.   In the third district will be found again a reduced height and a reduced percentage of lot area to be covered.   In outlying districts, contiguous

building, tenement construction, or building to the lot line is not permitted, and frequently only 40 per cent of a lot may be covered.

The constitutionality of the zone system has been tested in Boston, which has two zones, one for building 125 feet high maximum, and the other with a maximum of 80 feet. More elaborate zoning is now in practice in Minneapolis.

A zone system would inevitably involve the districting of factories if the welfare of the community is to be conserved. Where factories and tenements are mingled, the gases may render living conditions unhealthful or unpleasant. German cities very generally restrict their factories to quarters of the city in which available transportation facilities can be rendered of the best, and to quarters from which the prevailing winds will carry the smoke, dust, gases, and noise away from the city.

DECENTRALIZATION OF INDUSTRY.

One other adjustment of the factory and cottage home is ordinarily termed industrial decentralization. In England especially housing reformers have agitated for the removal of factories from cities into the open country where land is cheap and abundant, where transportation facilities can very frequently be rendered of the best, and where each worker can live in a cottage home. Such industrial communities may be established cooperatively, as in the case of the British " Garden City," or may be established by the owners of factories, as is the current American practice, the houses in this case being erected by the manufacturer either to rent or to sell on easy terms to his employees.

THREE METHODS OF REDUCING THE COST OF SUBURBAN LAND.

Cottage construction for workingmen is impossible at present wage rates unless land can be procured which is both accessible to work and cheap. Much of the suburban land in American cities is being held vacant to-day by speculators in the hope of reaping a large increase in land values. Accessible land is not easy to procure in small parcels. There are several ways, however, in which it may be rendered more available. German cities, for example, quite generally buy up their suburbs and then sell the land in small plots under heavy restrictions as to its future use or transfer, or else lease this land to home builders on long-term leases. By this means suburban land prices can be kept low, the city receiving the unearned increment of its land in the form of enjoyment by working people of its proper usage for homes, instead of receiving it in the form of taxes or rents. The city of Ulm, Germany, between the years 1891 and 1909, thus purchased 1,208 acres of land for $1,390,000, and sold 404 acres under

restrictions for $1,633,000, thus reaping from its transaction 804 acres of land, $242,000 in money, and the lowest tax rate in Wurtemburg.

Land prices may be similarly restrained or communities can democratically share the advantages accruing from the unearned increment of land by means of cooperative development. The Copartnership Tenants Societies formed by artisans, mechanics, and clerks in some 20 British cities, have thus bought patches of suburban land, from 10 to 300 acres in size, at reduced cost per unit; have developed such land cooperatively at reduced cost per unit for architect's services, laying of streets, plumbing, sewerage, etc.; have built their houses cooperatively, purchasing materials for 50 or more houses at once at considerably reduced costs. Each tenant pays rent for his cottage home to the Copartnership Tenants Society to which he and his neighbors belong, and receives his profits (aside from 5 per cent interest earned by his share capital) in the form of dividends on rents, paid not in cash but shares of stock in the society. The unearned increment of the land is the common property of the cooperating members and enhances their profits. The Harborne Copartnership Society in its garden suburb on the outskirts of Birmingham, England, was formed by workingmen who to-day pay rents for these cottage homes at rates no higher than they paid previously for insanitary slum tenements in the city. Yet this society is already able to pay 8 per cent dividends on rents in addition to the regular 5 per cent interest on invested capital. The British workingmen have, however, had more experience in cooperative methods than have the American workingmen.

This method of cheapening and facilitating suburban development is not applicable here without an intermediate period of careful study of cooperative methods by the workingmen who plan the association, and preferably should not be tried until they have had some experience in some form of cooperative practice. Garden suburbs of this character in England and in Germany have been facilitated by cheap loans of capital from philanthropists and from the governments of these countries. If capital might be obtained from some source at 4 per cent interest for building loans, and if the experiment had the backing of influential citizens, it would be much easier to make it a success.

A third means of reducing the cost of land per cottage would be by use of the land tax already described. If the tax were taken off improvements and placed exclusively upon the land, the vacant land now held in the suburbs by speculators would be placed upon the market or built upon. It is probable that land under such conditions would be more readily available to modest purchasers in the suburbs, and in so far would make suburban housing possible.

RESIDENTIAL STREETS.

Residential streets are often rendered costly through unnecessary width and through the expensive provision of curbs and sidewalks. Some residence streets must be used for a fairly large local traffic. Others are by their very nature and direction precluded from such use. A careful study of this problem will indicate that in certain suburban residential quarters the width of streets might easily be reduced to the provision of a 16 to 22 foot roadway flanked by grass strips. By establishing a building line on each side of such roadway at some distance from the street, it would be possible for the city to widen its streets without serious expense if that should ever prove necessary. The provision of sidewalks on both sides of the street is also not invariably necessary in suburban quarters where a street is purely local. If the street is developed only to such degree as to render it adequate for its local service, the cost of street construction will constitute a much less burden upon home owners.

SIZE AND SHAPE OF LOTS.

There are several serious disadvantages in having lots of uniform shape. In the first place a popular prejudice is created for the prevailing deep and narrow lot which is not easily dislodged, and the poor man who wishes to build a cottage home is socially constrained to purchase a lot 100 feet deep whether he needs so much land or not. It is, perhaps, the safest thing for a city to have standard lots, at least in the heart of the city, until the science of lot distribution and usage is developed. It is not easy to make a definitive prescription for the employment of lots of any other specific size which would be more satisfactory for all purposes. But the lack of elasticity in present lot shapes and sizes is fraught with serious consequences. The 25 by 100 foot lot can not be used economically for workingmen's cottages. It is wasteful of land at the rear, for the American workingman will not ordinarily start a garden as will the English or Italian. It is parsimonious of land at the sides of houses, especially if built in the two-flat style. It becomes impossible to construct two-flat houses on lots of this shape which will not be too near to the lot line and thus to neighboring houses.

If the arterial streets of a city are broad and sufficiently straight, and there are occasional broad cross streets within the residential zones, it should be possible to plan much of the remaining residential land with narrow dirt streets for local service purely, often, perhaps, with one sidewalk or none, grass strips and trees at the sides, and a building line for houses on abutting lots. These streets might wind, which would enhance their beauty: and if on a hillside, ought to

wind in some accordance with the contour lines of the hill. In such quarters, lots of varying shapes and sizes would be possible.

Near factory quarters, where land values are not yet prohibitive, the Philadelphia type of housing might be promoted by the establishment of lots of 14 or 15 feet in width and perhaps 40 feet deep, to be built up with 4-room or 6-room cottages, two stories in height, with brick dividing walls on the lot line. Houses of this type could be constructed so as to be available even for the families of day laborers, as the experience of Philadelphia has proved. Preferably if this type of house is to be used, builders should be provided by some competent authority with standard plans showing types of construction that are cheapest in design and at the same time healthful and varied in exterior. Multiple cottages of this type can be constructed to rent or to sell. Streets may be narrow without darkening rooms, but provision should be made for grass strips and trees on all streets of this character, relieving their monotony of type and improving the air for the semicrowded occupants.

In the outlying portions of the city's contiguous suburbs, both straight and winding streets may be provided, and in specific quarters lots narrow or wide, shallow or deep, may be accepted according to the prospective use of the quarter. In general, however, the narrow lot should be avoided in such suburbs, and the permission to plat deep lots might be granted, or parks or allotment gardens planned in the center of certain blocks if the city guarded the right to push a minor street through the middle of the block in the future. Both one and two family houses could be constructed more economically and to greater social advantage on lots from 30 to 35 feet in width and 60 to 70 feet in depth than they can now on the 25 by 100 feet lot. On the wider lot, as specified, houses can be constructed with square-floor plan, two rooms abreast and two or three rooms deep, reducing somewhat the cost of construction, the cost of heating, and the cost of furnishing such homes. Furthermore, the lot 35 by 60 feet in dimensions uses 400 square feet less of land than the lot of 25 by 100 feet. On it a house may be built with two rooms of ordinary size abreast and may yet leave 5 feet on the side to each lot line. The house may be built two rooms deep and leave a 10-foot lawn in front (insured by municipal provision for a building line) and a 25-foot yard in the rear, which may be encroached upon by a third room in the depth of the house or by a piazza, or may be used as a garden. The only serious disadvantage of this lot plan lies in that it provides for an increased street frontage, and thereby a larger cost to the owner for road construction, etc. But if street costs in residence sections are reduced by the means above specified, there will unquestionably be a net gain to society from the use of this method of platting.

Irregular lots on winding streets can be rendered economical and exceedingly beautiful if developed cooperatively in the manner already described. The British copartnership garden suburbs are so planned and yet are able to house workingmen at current rates.

PUBLIC SUPERVISION OF SUBURBAN DEVELOPMENT.

If your city is to determine its housing development, it is essential that there be a municipal commission empowered to establish (subject to district referendum) the building zones of the city, to pass upon, and, if necessary, reject plans of land companies for estate development, to determine also the direction, width, paving, and planting of new streets, with power to inaugurate schemes and enforce its decisions in so far as they affect vitally the welfare of the community. There should be a permanent city plan commission for the metropolitan district, even if the suburbs of the city are not all (as they should be) incorporated within the political city. There is much European precedent for the establishment of such commissions with power. German cities are so provided. English cities, under the town-planning act of 1909, may secure power to regulate the methods and extent of development of land likely to be used for building purposes within, or in the neighborhood of, their area. They also have power to limit the number of buildings which may be erected per acre and the height and character of those buildings.

In America city-planning powers of this type are already being given by provincial governments of the cities of Canada. In Ontario, for example, local town-planning commissions have power to pass on all lot distribution of towns of 50,000 inhabitants or more, and cities may plan for the area within 5 miles of their limits. No lots may be sold until such plans are approved. The value of this power is reduced in so far as the promotion of workingmen's suburban homes is concerned by the requirement that all streets shall be at least 60 feet wide. The provinces of western Canada have given quite similar power to their cities. In the States, somewhat similar powers have already been granted to cities in Pennsylvania and Wisconsin. And that power under the Wisconsin law regarding the platting of land near cities, adopted in 1909, extends to all land within 1½ miles of the limits of such cities.

THE COST OF COTTAGE CONSTRUCTION.

Suburban development will be encouraged not only by keeping low the price of land and restricting its use but also by any reduction that can be made in the cost of constructing cottage homes for working men. In general it is possible to construct tenement houses which

shall be cheaper per unit of accommodation than cottage homes. This will probably not be true where tenement houses are required to be fireproof. It is, however, advisable for citizens who are aware of the urgency of their local housing problems to experiment in the construction of detached and multiple cottages. The best ability of architects in America has been turned to monumental work, but the important social problem of designing cheap cottages has been almost overlooked by them. In England the attention of the best architects has been turned to this problem by the holding of competitions with prizes for the best cottage constructed for a specified sum (£175 in the case of the first cheap cottages exhibition, Garden City, 1905). The purchase of the houses constructed may be guaranteed by the promoting body.

It would be desirable to interest the best-trained architects of America in this problem, for by competition among them new arrangements of houses and new materials for construction will be brought to public attention. Such a competition might be held by a municipality (as, for example, one was held at Sheffield, England, in 1907), but such competition could be held with equal satisfaction by some private organization. The cost of cottage construction may be reduced also by large-scale building, buying and developing several acres of land at a time. This may be done by philanthropic associations, by employers of labor, by commercial building companies, or by cooperative associations of tenants. It is in experiments of the type above indicated that private organizations can do their best work in meeting the problem of promoting suburban housing.

THE ECONOMIC AND SOCIAL RÔLE OF FASHION.[1]

By PIERRE CLERGET,

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Fashion is a social custom, transmitted by imitation or by tradition. It is a form of luxury, luxury in ornamentation. Voltaire says:

> There is a fickle, teasing goddess
> Fantastic in her tastes, playful in adornment,
> Who at every season seems to flee, return, and rise again.
> Proteus was her father, her name is Fashion.

Many writers have sounded the caprices of fashion, its frequent coming, its suddennness. It is changeable,[2] unreliable, frivolous; the most careful calculations are often brushed aside for the most trifling causes. Another characteristic is its universal following. Domineering, it reigns supreme over all classes of society. While this "democracy of fashion" is quite recent, yet the taste for finery is as old as the world.

An English archeologist, Mr. Evans, found in the Mycenaean palace of Knossos in Crete some frescoes painted 1,400 years before our era, showing ladies of the court clothed in resplendent garments, with enormous leg-of-mutton sleeves held to the neck by a narrow ribbon; their flounced skirts, ornamented with embroidered bands, are expanded behind by enormous bustles.

Writings and monuments tell us that under the Empire changes of fashion and peculiarity in costumes were customary at Rome. During the Middle Ages, an author of the twelfth century wrote: "France, whose humor varies continuously, ought to have some garments which would proclaim her instability." In the fifteenth century, Robert Gaguin reproached Parisians "for always being eager for novelties and unable to retain the same style of clothing for 10 successive years."[3]

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[1] Translated by permission from the Revue Économique Internationale, Brussels, vol. 2, No. 1, Apr. 15–20, 1913.

[2] "One fashion has hardly brushed aside another when it is abolished by a new one and this in turn gives way to one which follows, but this one will not be the last."— La Brugère. "The new style of dressing makes the older fashion out of date, so forcefully and with such general agreement that it might be called a kind of mania which turns the senses round."—Montaigne.

[3] Cited by L. Bourdeau, Histoire de l'habillement et de la parure. 8° F. Alcan, 1904, p. 197.

Until the thirteenth century, women's costumes were chiefly tunics or robes, marked by plain and natural simplicity. It was only toward the fourteenth and fifteenth centuries, under Francis I and Henry II, that dresses were designed following the lines of the body. Women then appeared with fitted doublets, skirts, and wraps with collars. The sleeves were leg-of-mutton and balloon shaped, filled with plaits, or very tight, and these shapes often have been imitated in our day. This was the starting point of fashion which will sleep only for perpetual reawakening, making evolutions in irregular cycles at the will of its creators. Under Henry III we find the pointed waist, held in place by a stiff corset, the puffed sleeves; the dress already had the hoop-petticoat which fashion revived again in 1830.

The reign of Henry IV brought us the great bell skirt, built on springs, which we find later with the crinoline. This tendency toward fullness in the skirt kept increasing until 1605, bringing some dresses to enormous proportions, with ruffles adding to their size. Then, toward the end of the seventeenth century the fullness diminished, giving way to padded dresses, concealed under mantle wraps, and in 1880 they reappeared again. Reduction in the size of the skirt continued until about 1750 when fullness again came into fashion, and by 1785 the skirts were ridiculously full, expanded with great hoops. There was another reaction and the hoop-skirt gave way first to the bustle, then in 1793 came the one-piece dress, with a running string and without ornamentation. Greek robes were seen at fêtes and on the stage. The directoire dress, very close-fitting, exaggerated the plaited style and resembled the trousers skirt of recent date. The empire costume, with the waist high under the bosom, was only another transformation of the directoire dress, showing at that time a tendency to fullness in the form.

After 1805 the cycles began to shorten, the wheel turned faster, and without stopping, until we find a general style used by all classes of society. Skirts were worn very full again toward 1810 and, passing through all sorts of gradations, with a partial return of fullness in the back, ended in 1860 to 1865 in the culminating point of the crinoline. This marks the departure from Orientalism and brings us toward the epoch when very simple and straight robes were worn until we reach the other extreme, the clinging gown, not forgetting the harem skirt, an exaggerated revised edition of the eccentricities of the period from 1805 to 1815. We must pause to resume slowly but surely the march toward the puffed or padded styles.[1]

How is fashion created? Since the days of Worth in 1846, it has been the well-known modiste who has been the creating artist. His

[1] Bulletin des Soies et des Soieries, Aug. 18, 1911.

popularity is such that it has become a regular habit to visit his establishment, and as Pierre Mille[1] says, "he knows how to make the worldly minded dress and how to prattle," as shown by Gervex's painting "chez Paquin à cinq heures." The modiste seeks out the designs, fits the forms, harmonizes the lines and styles. Each establishment decides upon a model and then selection is made from public opinion expressed at the great gatherings at Auteuil and Longchamp. Each modiste has a representative there and in broad daylight they make comparisons, listen to criticisms, make after-touches, and the "complete results of the races" told in the Paris evening papers omit the most striking act of the day: Fashion was born and a humble seamstress may have had the chance to invent it.[2]

The fashion created, there is haste to make it known, to launch it. Under the monarchical régimes and under the first and second empires, the court fulfilled that duty and gave fashion some distinction. It is only since the first Republic, or particularly since the third Republic, that the prevailing style has been anything more than the reflection of the will of the sovereign whose ideas and customs had the force of law. Under the first empire, Josephine abhored a stiff style of garment; she preferred the low-neck gown with high waist and flexible skirt; her hair arranged with the bandeau. Roman art then ruled, brought about by Josephine. Empress Eugénie had like influence under the second empire, and to her we owe the taste for a comfortable style, and stuffed, silk-covered furniture.[3]

To-day the style is made public by mannequins at the race course, on the street, at the theater, by actors on the stage, and by such social functions as a wedding or a ball. The fashion at the theater seems to be playing an increasing rôle. Fashionable modistes have recently announced their intention of having their mannequins replaced by actresses, who on the stage, by their grace, their elegance, their beauty, their prestige, would tend to a more ready acceptance of fashion's extravagant innovations. Madame Jane Hading, in the play of L'Attentat, introduced the dress known as the "aile de cabeau" or winged pannier. And Madame Martha Brandès created the style of sleeves since known by her name. When La Walkyrie was first presented at the opera, white wings like those attached to Brunehilde's helmet were worn on hats, and the armor of the warlike maiden gave to dressmakers the idea of spangled robes, much resembling the breastplate. The use of pheasant plumage became more

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[1] Pierre Mille: Une des industries intellectuelles de Paris, la grand couture. Revue économique internationale, May, 1912.

[2] Bulletin des Soies et des Soieries, Nov. 10, 1900.

[3] E. Mazille: Comment se crée la mode dans l'industrie de la soierie. Bulletin trimestriel de l'Association des anciens élèves de l'Ecole supérieure de Commerce de Lyon, March, 1908.

general after the presentation of Chanteclair. We already had the "Dame Blanche" fichus, and the Lutheran bonnet was popular after Les Huguenots was played.

Any striking idea may inspire a fashion. Under Louis-Philippe "all the fashionable young men of the capital wanted their trousers plaited at the hips like those of the African chasseurs; they had their turbans and their Arab checias (skull caps) at their homes."[1] Trocadero ribbons became the rage as a souvenir of the voyage of the Duke of Angoulème to Spain, and the Russo-Japanese War gave us the kimono. It is to the passion for sports that we owe the English styles, the success of the tailor-made costume, the fashion for furs and leather garments, and also that "war hat" attempted by some Americans.

Literature also has been a great inspiration, as shown by the curious and interesting book of Louis Maigron on "Romantisme et la Mode." The essential characteristic of the romantist revolution was the return to national tradition, the style of the Middle Ages, which forced itself quickly and in every direction, taking the place of the empire style. According to Mons. Maigron, "romanticism creeps from books into the daily life through social diversions." The masquerade thus makes some pretensions, often justified, of reconstructing history; old engravings are appealed to for aid in costuming.

The works of Victor Hugo, especially Hernani, have had an influence on fashion as great as pre-Raphaelism has to-day on gowns and hairdressing. The use of white muslins was the inspiration of Taglioni, as were the "waves of the Danube" taffetas. The "Atala" collars and the "Marie Stuart" hats were successively worn. The "battlement" hat was designed in part from a headdress looked upon as that of Jeanne d'Arc. and likewise the "leg-of-mutton" sleeve recalls the costume of the sixteenth century.

There is a complete revolution in the work of gold- and silversmiths. Jewelry is made in the shape of pointed arches with knights in steel armor, pages with plumed toques, helmets, grey hounds, coats of arms, escutcheons. A complete feudal arsenal is designed in chased work and enamels. In architecture the Gothic comes into full vogue, and it is constantly the romance styles which are most fashionable.

The red waistcoat of Theophile Gautier had its imitators; the waistcoat was at one time the chief thought of young Frenchmen. It is all a program that one cultivates and lives up to. Men's fashions extend to lace facings, braids, furs, Merovingian style of hair, and whiskers of an Assyrian king; the cravat is of a gloomy black.[2]

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[1] Louis Maigron Le Romantisme et la mode. Champion, 1911. Cf. also O. Uzanne: Un siècle de modes féminines, et la française du siècle. H. Bouchot: Le luxe français: Challamel: Histoire de la mode.

[2] L. Maigron, op. cit., passim.

It is this individualism directing the present style, this instability, the changing at every season, which helps Paris in great measure to maintain its leading influence on fashion, and this is not of recent origin. Isabel of Bavaria, in 1391, and Anne of Brittany, in 1496, sent to the queens of England and Spain dolls dressed in the latest style. During the war of the succession in Spain the courts of Versailles and St. James accorded safe conduct to the alabaster doll which accredited the newest fashions from the other side of the Channel.[1] It is Paris that "decrees the sumptuary law of nations," it is she that sells the models, and the best advertisement of a foreign modiste is to announce her "return from Paris." One can understand that this advantage would be envied outside of France, and they have tried, especially in the United States, to wrest it from her. These attempts have not ceased. It can readily be seen that there is involved in this the question of a convenient center which is not found elsewhere. Copying styles is so very easy that a committee of defense of Parisian fashions has been formed, which has brought about a closer connection between the release of models and the opening of the season, and there has been adopted a stamp of origin, furnished by the syndics of needlework.

While we have spoken up to this point simply of clothing and hairdressing, we should not think that this is the limit of fashion's domain. It controls conversation, the manner of walking, how to shake hands. Such a word as "épatant" (stunning) owes to fashion its recent admittance to the "Dictionary of the Academy." The general use of such a drink as tea, the abandonment of wine in certain circles, vegetarianism, may all be regarded as fashions, likewise the adoption of some state of the mind which takes the lead at times, as sensitiveness or calmness. We have already spoken of architecture and furniture. The passion for traveling and for sports becomes widespread; there is less taste for home; there is less desire for books and interior ornaments.

The influence of fashion is reflected also on the sales of works of art. The great sales recently held in Paris have shown that there is a revival in favor of productions of the eighteenth century. In June, 1912, at a Doucet sale a pastel of "Quentin de la Tour," the portrait of "Duval de l'Epinoy," purchased in 1903 for 5,210 francs ($1,042), brought 660,000 francs ($132,000); the "Jardin de la ville d'Este," by Fragonard, which sold for 700 francs ($140) in 1880, brought 21,300 francs ($4,226); and the "Sacrifice au Minotaure," by the same painter, for which 5,300 francs ($1,060) was paid in 1880, was held at 396,000 francs ($79,200). Such fluctuations, of which we could give many examples, are attributed by M. Paul Leroy-

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[1] V. du Bled. Les évolutions du luxe dans la Société polie. Revue Économique International, September, 1906.

Beaulieu to certain notions, among which fashion forms a large part; the personal satisfaction of connoisseurs, the desire for distinction, snobbishness, which is a grand master in fashionable life, the spontaneous adaptation of art of the eighteenth century to conditions of contemporary life and the development of large fortunes.[1]   In the statistics of foreign commerce works of art show the greatest change; in the fiscal year 1911–12 the importation of that class into the United States rose to more than $36,000,000, an increase of 60 per cent over 1910–11.

Other industries are also answerable to fashion—the fur trade, ornamental plumes, jewelry, toys, and artificial flowers. The style in furs changes every year, from the tippets to the stoles and scarfs of to-day, and the consumption of skins increases in enormous proportions.   In 1848 there were sold in London at public auction 225,000 muskrat skins, at a maximum price of 2 cents each; while in 1910 sales reached 4,000,000 pieces, at a maximum price of 14 cents. Russian ermine, which in 1888 were valued at 15 copecks (11 cents), sold in 1910 for 4.30 roubles ($3.25); beautiful sable skins, which sold for 5 roubles ($3.75) in 1880, brought up to 800 roubles ($600) in 1910.[2]

Artificial flowers, originating in China, now used more for hats and similar purposes than in decorating rooms, give employment in Paris alone to 10,000 women and 3,000 men, receiving $2,200,000 in wages, for a production valued at $6,700,000. The manufacture of toys is regulated almost exclusively by the current demand; it is enough to say that a toy is fashionable. The industrial arts peculiar to the colonies seem again to have come into favor after having been for a long time out of style. And it is to fashion that is due the present prosperity in false hair and perfumery trades. Each year 130,000 kilograms of hair are utilized in France, and the importations from China and Japan vary from year to year with change in style, from 8,000 to 16,000 kilograms. The fashion for rouge is as old as the desire of women to look beautiful; in very general use in Roman times, it revived with the Renaissance, when the habit spread even to the nuns. Madame de Sévigné wrote: " Rouge may be regarded as the law and the prophets; it is all christianity." Rice powder and " crème Simon " have no less success to-day than has the tinting of the hair. Finally, fashion is advantageous in the constantly increasing love for sports and travel and in the development of industries connected with these, particularly the hotel business.

What are the economical results of fashion? In the industrial world, first of all, it seems to be a stimulant to production; but it is

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solely in objects to which it offers itself, for the estimates are not elastic—an increase in one article leads to retrenchment in another, and the demand is merely changed from one industry to another. Thus enormous fluctuations are shown each year in the silk industries, on which the uncertainties of fashion are most particularly centered.[1] Ribbon is most affected, being much used, both on hats and clothes. It loses first one fashion, then another, and the evolution is tending rapidly toward the cheapest grades used so much for ornaments and in the thousand little gewgaws of women. The situation in dress goods is hardly any brighter, following the alnage law, showing from this that the close-fitting costume continues to be the style. "Praised by some, condemned by others," as the Figaro says, this fashion will leave in the history of textile industries the souvenir of an ill-omened influence. The quantity of material needed to make a costume has been reduced one-half or two-thirds, and, besides, it does away with undergarments and linings, which for many years represented a very heavy employment of tissues of plain silk. The inspector of silks at Lyons showed a registration of 7,590,445 kilograms of silk in 1911, as compared with 8,344,566 in 1910, a difference of 9.03 per cent. The two inspectors at Milan show still greater decreases of 15.60 and 9.68 per cent, respectively. An analogous reduction took place in the woolen goods industries. The French Chamber of Commerce of Montevideo complained last year of the effect of measurement inspection on the exportation of woolens. All the related industries of spinners and weavers were affected in the same degree, and the dyers, dressers, and stampers.

As Mons. Maurice Deslandres has ingeniously expressed it, fashion not only displaces the products of one industry by those of another, but also impedes the latter industry by demanding quick changes in machinery; retards it until the last moment by some extensive changes in the work, and the trend is steadily toward low prices and inferior qualities which are not durable. The result is to raise the net cost by requiring the manufacturer to make earlier settlement for apparatus, and necessitating expenses for the setting up of new models.[2]

From the commercial standpoint there is a tendency to an increase in prices because of manufacturers stocks unsold, and the hesitation of jobbers to lay up large supplies. The relations with customers are no longer easy, the latter delay their orders, are undecided about their

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[1] It is interesting to compare the fluctuations of the silk industry (as capricious as those of agricultural productions) with the regularity of other industrial products influenced only by periodical crises, cf. the chart in our "Manuel d'économie commerciale." A. Colin, Paris.

[2] Maurice Deslandres. La mode, ses conséquences économiques et sociales. Bulletin des ligues sociales d'acheteurs, vol. 1, 1912, pp. 25–37.

choice, require more urging, and all the orders begin to accumulate during the last days preceding the opening of the season.

In the agricultural world, fashion has produced transformations no less serious, some of them unfortunate. The abuse of ornamental feathers has brought about the destruction of all sorts of birds which had protected the crops against the ravages of various insects. It is to the democracy of fashion, as well as to its instability, that we must attribute the conditions in textile manufactures, where we find a reduction in the use of flax, an enormous increase in cotton, and the displacement of vegetable dyes by the more brilliant though less serviceable dyestuffs derived from coal tar. In the animal world certain species of fur animals are on the verge of extinction, and there should be either attempts at domestication, as in the case of the blue fox and the opossum, or hunting regulations by the creation of open districts with complete prohibition during a certain period. In Siberia a recent law suspends the hunting of the sable from the 1st of February, 1913, to the 15th of October, 1916. Likewise an international agreement between England, Canada, Russia, Japan, and the United States prohibited May 11, 1911, the hunting of fur seals in the open sea of the North Pacific.[1]

The present democracy of fashion is the great social factor to be emphasized. It has encouraged a great consumption of products; a depreciation in quality and prices; it has induced a very great instability, which disconcerts both producers and buyers; manufacturers must make the same classes of products for all markets; fashion is followed at the same time by all classes of society. The wheel turns quickly and ceaselessly. On the other hand, these rapid changes do not take place without a slack season for the workman, without quick fluctuations in salaries, or without change of specialization.

" To follow the fashion " becomes not only a pastime, but even a duty; " intellects are made frivolous thereby; those who pride themselves in appearing elegant are obliged to make the clothing of themselves a veritable occupation and a study, which assuredly does not tend to elevate the mind, nor does it render them capable of great things."[2]

To this moral and social evil an economic difficulty is also added. Fashion is a waste; " it has the privilege of casting things aside before they have lost their freshness; it multiplies consumption and condemns that which is still good, comfortable, and pretty for something that is no better. Besides, it robs a State of that which it

[1] On this subject see our work. L'exploitation rationelle du globe, 1 vol., Doin & Son, 1912.

[2] E. de Laveleye, quoted by E. Picard. Le luxe et les grandes fortunes. Revue Économique Internationale, July, 1905.

consumes and that which it does not consume."[1]   Mons. Pierre Mille told recently in this Revue of patrons who spent as much as $60,000 each year, others up to $16,000, and a still greater number up to $5,000. But it is mostly among the middle and laboring classes, whose means are more limited, that unreasonable expenditure in following fashions is most harmful.

These abuses, this tyranny of uniformity in nearly all outer manifestations of life, leads notably to the banishment of provincial costumes, the representatives of climate, products of local art, so full of interest from an historical standpoint, picturesque, stable, durable, which are handed down from generation to generation. Among these costumes of historic interest are the Caux cap recalling the steeple headdress of ladies of the fourteenth century; the little Nicæan hat reproducing the coiffure called "Thessalanian" by the Greeks, and the antique Phrygian hat, still worn by the Arlesians. Although formerly there was variation according to place and uniformity as to the season, we now tend more and more toward a uniformity as to place and variation as to season.

The abuses denounced, it would be useless to demand, on the contrary, an immutability in complete opposition with the transformations of all sorts which surround us. Tertullian in his treatise "De pallio," says that nothing is more natural than changing the costume and that nature sets us an example in assuming varied forms. Human fancy thus asserts its supremacy over animals, obliged always to wear the same livery. Austere philosophers have understood perfectly the esthetic and social significance of fashion. Renan, writing on Marcus Aurelius, admits that " woman in dressing herself well fulfills a duty; she practices an art, an exquisite art, in a sense the most charming of arts. * * * A woman's toilet, with its refinements, is a great art in its way. Ages and countries which know how to carry it out well are great ages, great countries."

The appearance of a new style of garment is the visible sign that a transformation is taking place in the intellect, customs, and business of a people. The rise of the Chinese Republic, for instance, led to doing away with plaited hair and to the adoption of the European costume. Taine wrote this profound sally: "My decided opinion is that the greatest change in history was the advent of trousers. * * * It marked the passage of Greek and Roman civilization to the modern. * * * Nothing is more difficult to alter than a universal and daily custom. In order to take away man's clothes and dress him up again you must demolish and remodel him."[2]   It is also an equally philosophical conclusion which Mons. Louis Bourdeau gives in his interesting " Histoire de l'habillement et de la parure": "There

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[1] J. B. Say, quoted by E. Picard, op. cit.
[2] H. Taine. L'Italie et la vie italienne. Revue des Deux-Mondes, 1865.

where the same style of clothing is used for centuries, as among barbarous peoples, one has the right to say that civilization remains stationary. There, on the other hand, where, as in Europe, garments are subject to continual modifications, one may see evidence of great comfort and rapid progress. * * * Far from being a custom of incurable frivolity the changes of fashions mark a high civilization, subject to change because it is growing and because it has wide latitude to refine its ideal in proportion as its productions are varied." [1] Again, it is necessary that that versatility and refinement be not turned to extravagance or to impropriety, compromising the reputation for good taste, elegance, and distinction which the fashions of Paris enjoy throughout the entire world.

What can we do for or against fashion? Can we direct it or can we prevent its abuse? Let us find out first the power of the law, religious or civil. Very early popes and councils strove in vain against the low-neck gown and the dresses " terminating in the serpent's tail." Kings imitated them, Charlemagne setting the example, but sumptuary decrees have had no more effect than ordinances against dueling. Mons. Victor du Bled reports that Philippe le Bel was urged to promulgate some sumptuary laws by his wife, who, making her formal entrance at Bruges in 1301, saw a crowd of common people so richly clothed that she cried out with vexation, " I thought myself the queen, and I see hundreds of them." Charles IX proscribed hip pads of more than 5 feet, gold chains, pieces of jewelry with or without enamel. In 1567 he regulated the garments of each class, permitting silk only to princesses and duchesses, forbidding velvet. But these laws were intended very much more to limit foreign importation and to encourage home industry than to regulate fashion. [2] Seventy-two decrees prohibiting the use of India cloth were rendered from 1700 to 1760 and proved to be powerless against the rulings of fashion. In 1706 a certain French chamber of commerce voted " that officers may have the power to arrest on the streets persons who are found clothed in this kind of goods, and they should be condemned to pay a large fine." In 1912 another chamber of commerce voted for ministerial intervention against some noted dressmakers to check the use of clinging dresses, against which the American clergy and some members of the German medical corps preached without success.

The intervention of manufacturers injured in their interests by reduction to the metric system or the abandoning of such and such an ornament is of no effect. A committee of propaganda, formed at Saint-Etienne with a view to reviving the fashion for fine qualities

[1] L. Bourdeau, op. cit., p. 195.
[2] V. du Bled, op. cit. Cf. Dr. A. Velleman, Der Luxus in seinen Beziehungen zur Sozial-Oekonomie. Halle, 1898.

of ribbon, has produced no appreciable result. Those only have influence upon fashion who make it and promote it, those who offer it and those who can refuse it—the tailor and the customer. The first is too much concerned in the changes of fashion to expect him to make any effort to restrain them; the second is quiet, provided that he be included. If fashion responds to an innate tendency of our nature, the fondness for change, the actual rapidity of this change is neither disastrous nor necessary, as the long use of the tailor-made costume shows. The last word shall be given to the social leagues of buyers and the leagues of consumers, because of the very interesting initiative taken by the former in favor of handmade lace with a view to reviving that valuable rural industry. After having brought about the assembling at Paris of an exposition of women's work, they asked their members simply to require mention of the origin "handmade" or "machine-made" on the laces put on sale.

THE WORK OF J. H. VAN'T HOFF.[1]

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Jacob Henry van't Hoff was born August 30, 1852, in Rotterdam, where his father was engaged until 1902 in the practice of medicine. His ancestors had for centuries held the positions of alderman and mayor of the little village of Groote Lind near Rotterdam. He descended, therefore, from one of the ancient families of those austere and sturdy Dutch burgesses which the paintings of so many artists portray, gathered in civic councils, in learned assemblies, and in companies armed for the defense of the fatherland. The external traits of this strong race were reproduced in his countenance, and in his character were found its best moral endowments.

The beginnings of his scholastic career were modest; he attended the elementary schools and took his secondary school work in his native town. His parents seem not to have had great confidence in his future. It is certain, at all events, that at first they did not approve of his desire to devote himself to the study of pure science—the subject toward which he felt himself drawn. He was obliged to commence by registering in the Polytechnic School at Delft, where at the end of two years he took his final examinations and obtained the diploma of technologist.

After having thus satisfied his family by securing a professional diploma, he finally obtained the permission he so much coveted, to devote himself to scientific study, and registered in 1871 at the University of Leyden, the oldest and most famous center of education in the Netherlands. There he studied mathematics and physics, but devoted himself more especially to chemistry. In 1873 he went to Bonn, where he worked for some months in the laboratary of Kékulé, and did his first experimental work. [We shall see later what influence his stay in Bonn was to have on the development of his ideas.] He remained for a shorter period in Paris, where he frequented Wurtz's laboratory. [We shall soon see what a deep impression was made upon him rather by the works of Pasteur than by the ideas of Wurtz.]

Returning to his native country, he took up his studies at Leyden again, and in September, 1874, published a brief paper in Dutch, in which he stated fully and succinctly all the essential portion of the stereochemical theory. This publication, the outcome of which we shall discuss later, preceded by two months a similar publication by Le Bel. The young man did not venture to present this work as a thesis for the directorate, but preferred to confine himself to a modest dissertation on cyanacetic and malonic acids, with which thesis he obtained his degree of doctor of philosophy December 22, 1874.

The following year we find him in search of an occupation which should be suitable to his taste and, above all, would permit him to continue his chosen studies. His first attempt to obtain a modest position as professor in the technical school at Bréda was unsuccessful. Amusing, and at the same time touching, is the letter which the director of this school wrote to the minister of public instruction, describing to him this young man, with distraught air, with the appearance of an inventor, entirely absorbed in his great visions and seeing only his atoms and their valences disposed in space; he concluded by saying that, according to his judgment and the unanimous opinion of the colleagues of the school, van't Hoff was not the man for such a position.

In 1876 van't Hoff was finally made docent of the veterinary school of Utrecht, where he stayed but a little more than a year, being called as lecturer to the new university which the city of Amsterdam had just founded. He was not slow in gaining the esteem and consideration of his superiors, and as early as 1878 was made professor of chemistry, mineralogy, and geology. He occupied this position for 17 years; that is to say, until 1895. To this period, which is the most important of his scientific life, belong his great works on chemical equilibrium and on the theory of solutions. It was the period of extraordinary growth of physical chemistry, and van't Hoff was soon universally recognized as the most gifted representative and the best authority of the new school of which Ostwald was the unrivaled propagandist.

His fame grew rapidly; in 1887 the University of Leipzig invited him to accept a chair, which he refused; in 1889, when scarcely 37 years of age, he was made honorary member of the German Chemical Society, an honor aspired to by the greatest scientists. Finally, in 1896, the University of Berlin called him in a specially honorable way; he was made honorary ordinary professor, without being placed under the obligation of teaching; the Academy of Sciences made him an active member, and furnished him the means to establish a laboratory for research. In this laboratory he devoted himself for 10 years to the investigation of the conditions of formation of the saline deposits at Stassfurt, the first great attempt to apply the

physicochemical theories to the studies of geological phenomena. In the meantime, in 1901, the Academy of Sciences at Stockholm gave concrete form to the universal opinion of chemists by conferring on him the first Nobel prize for chemistry.

In the autumn of 1906 there appeared the first symptoms of the terrible disease to which he was destined to succomb; after a sojourn in a sanatorium he apparently recovered * * * but a relapse soon followed, and on the 1st of March, 1908, his life ended at Steglitz, Berlin; a life which was too short, if one considers the number of years passed; simple, if one thinks of the tranquility of exterior events; great, as few others, if one reflects on the enormous amount of work which it represents.

After thus broadly tracing the general biography of this great scientist, we may begin the examination of his life work. And this, with the exception of his first researches in organic chemistry, a few works of fragmentary character, occasional publications and resumés, may be divided into four main divisions: Stereochemistry, the studies of chemical equilibrium, the theory of dilute solutions, and investigation on the saline deposits of Stassfurt. The second and third of these chapters overlap in their chronological development and show numerous logical connections with each other.

The creative period of the stereochemical theory is exceedingly short, lasting but three years, from 1874 to 1877.

The Dutch paper of 1874 contains in its 14 pages all that is essential. The author points out first that all substances then known which, in a liquid or dissolved state, rotate the plane of polarized light, contain in their formulas at least one "asymmetric" carbon atom—that is, a carbon atom combined with four atoms or groups differing from one another. In seeking the cause of this relation, he remarks that if one imagines the four valences of the carbon atom directed toward the vertices of a tetrahedron, of which the atom itself forms the center, the presence of such an asymmetric atom is the necessary and sufficient cause of the existence of two figures in space, of which one is the mirror image of the other; hence the presence of two isomers, one dextro-rotatory, the other levo-rotatory, and of one inactive compound resulting from the union of both, and capable, by separating, of forming them again. The existence of such isomers and the possibility of separating them had been demonstrated for the first time by Pasteur, 10 years before, in the case of tartaric and racemic acids.

In this respect the considerations developed two months later by Le Bel agree with those of the young Dutchman, except as to form. But on one point, the latter pushed them further; he foresaw that in unsaturated compounds in which two carbon atoms united by a double bond have their two other valences united with two other

atoms or groups, differing from each other, two isomers in space may be formed which not being antipodes are not optically active; isomers of which we have examples in fumaric and maleic acids.

If we wish to seek for the origin of the stereochemical conception in van't Hoff's mind, we must recognize first of all the preponderant influence which the doctrines of Kékulé had upon him, an influence which had been increased during his stay in Bonn. With his doctrine of the valence and particularly of the tetravalence of carbon, with the development given to the theory of the structure which attained its apogee in the statement of the theory of the constitution of aromatic compounds, Kékulé had made of the University on the Rhine a center from which radiated new ideas on organic chemistry, and had grouped around him a crowd of brilliant pupils.

A few years before, there had left Bonn for Italy a young German chemist, W. Koerner, who was to publish in the same year his classical researches on the determination of position of substituting atoms in aromatic substances—another brilliant extension of Kékulé's theory. The coincidence is not without interest. The tetrahedral model of van't Hoff was identical with that which Kékulé had already used in his demonstration. In each case Kékulé had given the model, but he lacked the confidence to use it in all the legitimate deductions and representations which one could obtain from it.

Naturally the van't Hoff innovation was much more radically revolutionary, since for the first time structural formulas were employed to indicate not only the order in which the atoms are linked among themselves by their valences, but also, necessarily, their manner of distribution in space.

Pasteur, after having thoroughly studied the nature of these peculiar isomers, had already pointed out intuitively that the cause of this asymmetry must lie in a molecular asymmetry, since it does not disappear, as in quartz, with the disappearance of the crystalline form, but persists in the liquid or dissolved state. He had foreseen that the atoms must be disposed in their molecules so as to give two figures corresponding between themselves like the crystals, or, for example, like a right and left spiral.

But Pasteur could not reach the complete solution of the problem for lack of a suitable model. Van't Hoff was to succeed when he applied the Kékulian model, and after having grasped at one careful glance the already abundant data, he saw like a flash that the cause which he sought was none other than the presence in all the optically active compounds of an asymmetric carbon atom. If one seeks for the cause of the differences between the ideas of van't Hoff and of Le Bel and of the less complete character of the latter, it may readily be seen in the fact that the theories of valence and of structure had not yet found in France the reception and diffusion which they deserved.

The speculations of van't Hoff and Le Bel were received at first in silence and with general indifference. In 1875, when he found himself again face to face with difficulties in finding a position, the young Dutchman published a French translation of his first paper, under the title " La chimie dans l'espace."

The new theory had to undergo its first test at a meeting of the Chemical Society of Paris in 1875, when van't Hoff had presented an abridged account of his ideas. Berthelot, still a young man, but one whose eminent works in the various domains of chemistry had already made him a great authority, rose for the attack. He declared that, without wishing to refuse a priore the space formulas proposed by van't Hoff and Le Bel, which had a certain advantage over the usual structural formulas in one plane, we could expect no result from the new theories, until we should learn how to recognize the vibrations of the atoms in the interior of the molecule. Later he raised other objections of a more positive character, for example, the existence of substances optically active without asymmetric carbon atoms. Van't Hoff, Le Bel, and other experimenters replied to these objections by demonstrating that the supposed contradictions came simply from errors of observation.

Meanwhile an important step was taken with a view of making the new theories public. A German scientist, well known by his works on organic chemistry, Wislicenus, professor at Wurzburg, who some years before had recognized the insufficiency of structural formulas to explain certain cases of isomerism, became acquainted with the fundamental note of van't Hoff. Being struck by it and comprehending its great importance, he had his assistant, Hermann, make a German translation of it. This, supplied with a preface by himself, was published in 1877, under the title " Die Lagerung der Atome in Raume." This publication, which gave the widest notoriety to the theories of van't Hoff, had as an immediate effect the arousing of new and violent controversy. Hermann Kolbe, already an old man and famous, one of the scientists who had contributed most to the experimental development of organic chemistry and one of the most influential chemists of his time, well known as a bitter critic and violent polemist, who saw in the structural theory an unjustified and dangerous misuse of hypotheses, published a paper entitled " Zeichen der Zeit." from which it is interesting to quote a few passages:

I have already shown that the cause of the present decadence of chemical research in Germany lies in the lack of a solid general culture. I see one consequence of it in the reappearance of the weed of a natural philosophy. clever and brilliant in appearance. but in reality trivial and without meaning. It was driven out 50 years ago by exact research. but it has just been discovered again by a pseudoscientist, and like a courtesan. disguised à la mode and painted fresh. tries to introduce itself underhandedly into good society, to which it does not belong.

If this seems exaggerated one should read the writings of a Mr. van't Hoff, full of bad tricks of the imagination, which I should prefer to ignore if a distinguished chemist had not given him his patronage. This Dr. van't Hoff, employed in a veterinary school at Utrecht, takes no pleasure, it appears, in exact chemical research. He has found it more comfortable to mount a veterinary Pegasus and to announce how, in his mad flight through a chemical Parnassus, the atoms have appeared to him to be scattered in space.

Such a method of treating scientific questions which is not too far removed from a belief in sorcery and spirits is considered legitimate by a chemist like Wislicenus, whom we have always known as a serious scientist. By this act he excludes himself from the ranks of exact scientists and enters the category of those natural philosophers of evil fame whom only a subtle medium separates henceforth from the spiritists.

To this phillipic our scientist made a most sober and serious response. He prefaced to an article published in 1877 a few dignified but not unforceful words, and in October, 1878, as professor at Amsterdam, he opened his course by reading from the text, Kolbe's attack, taking occasion not to open a direct dispute but to defend serenely the importance and legitimacy of the intervention of creative imagination in the exact sciences.

But the address of Kolbe was no more efficacious than the objections of Berthelot in barring the way of stereochemistry in its march toward success. Hans Landolt, the best authority in the domain of chemical optics and polarimetry, realized that the new views were in accord with the facts of experience; and Piutti was one of the first, with his researches into the stereo-isomeric asparagines, to bring new facts to the aid of the new theory. More important still were investigations carried on in Germany after 1885. Besides those of Wislicenus on the stereo-isomerism of unsaturated compounds, we must remember those of A. von Baeyer on the stereo-isomerism of the hydroaromatic compounds and on the stereochemistry of cyclic compounds in general.

But the new doctrine obtained its greatest triumph when Emil Fischer, using it as a foundation, was able to solve for the first time the great problem of the composition of sugars. This impenetrable forest, which had defied until then the efforts of chemists, became suddenly light when an experimenter of such exceptional value held in his hand the thread of Ariadne, which alone could guide him toward the goal.

The succeeding history is only a succession of new conquests. V. Meyer and Hantzsch and Werner have shown that in the unsaturated nitrogen compounds like oximes, there could occur isomers of the cis and trans types; it is thus that the stereochemistry of nitrogen came into existence. Still more recent researches, among which we must mention first those of Pope, have demonstrated that when an atom of any tetravalent element whatever becomes asymmetric, this causes the appearance of optical activity and the existence of two stereo-

isomers. We have thus optically active compounds containing an asymmetric atom of sulphur, selenium, silicon, tin, and lead. Even pentavalent atoms like those of nitrogen and phosphorus may give rise to the formation of stereo-isomers, as Le Bel was the first to show.

To-day, after a lapse of 37 years, we can see that few theories have been able to achieve such triumphs. There does not exist to-day a single well-established fact which had not been anticipated, at least in germ, in the memoir of 1874. It would not be out of place to add here a few words with the purpose of examining more closely the intrinsic merit and amount of originality in the work of van't Hoff and Le Bel, for it is not unusual to read or to hear rather unsatisfactory statements relative to them. It is said sometimes that the merit of the Dutch scientist consisted in having imagined and introduced the tetrahedral model or in having first had the conception of the spacial distribution of atoms in the molecule. Nothing is more erroneous, or at least more superficial, for in this connection van't Hoff and Le Bel had several predecessors. The tetrahedal model was a necessary consequence of the conception of Kékulé, who had used it himself in its present form without, it is true, giving it the wide application which we give it to-day. And, as we have already said, Wislicenus had affirmed in a general way the necessity of having recourse to spacial configurations to explain certain isomerides. Earlier still, in 1869, Paternò had proposed to use for this purpose precisely the tetrahedal arrangement. It is not, then, in this that the merit of van't Hoff lies, but rather in the fact that he was the first to conceive the brilliant idea of the significance of the asymmetric carbon atom, and, also, after attentive and rigorous examination of all the facts already known, gave to the theory its definite form, so that one may say that it sprang, like the classic Minerva, already armed from the brain of Jupiter.

But from 1877 on van't Hoff no longer took a direct and creative part in the further development of the doctrine which he established. He nevertheless followed it always with an attentive eye and marked its progress in the successive editions of his books, among which we shall mention particularly " Dix années dans l'histoire d'une théorie," which offers a fine example of how to triumph with modesty.

But it is time to return to the year 1877; that is, to the moment when our young hero took up his work at the University of Amsterdam. He had made his début three years before. He was only 25 years of age and had already established a theory which was sufficient to pass his name on to history. All the immense field of chemistry stretched before him; his eye could not fail to discern in it new paths which were to lead him to still more brilliant triumphs.

The scientific production of van't Hoff underwent at this time a period of arrest, due, perhaps, to the loss of time that the necessity of adapting himself to new conditions of life and work imposed on him, but certainly for the greater part to the intellectual need of concentrating and orienting himself, before starting out again. However that may be, it is certain that during a period of seven years, from 1878 to 1884, he published no original papers worthy of engaging our attention. He did publish, however, a very interesting book, "Ansichten über die organische Chemie," now out of print and almost completely unknown, but which has considerable importance for one who wishes to follow the evolution of his scientific thought. He described this evolution himself in an address given in Berlin in 1892, which we shall have occasion to mention again more than once.

He pointed out in this the fact that even his first works on the asymmetric carbon atom must be considered, from one standpoint at least, as an attempt to contribute to the solution of a problem which had seemed to him from the first and which is in reality the fundamental problem of general chemistry—to discover the relations between the chemical constitution of substances and their physical properties and general behavior.

This problem he set himself to treating in a more general and systematic way in the book we have just mentioned, and then there appeared to him suddenly the great gap which made impossible the rational execution of his vast project; that is, the gap resulting from the almost exclusively qualitative character of the data of organic chemistry, as far as concerns the mechanism of the reactions * * *.

One single branch was developed quantitatively, that of thermochemistry; but at bottom the mass of data collected had not led to the great results that had been hoped, and there had been manifested in this field tendencies which were theoretically not rigorous. Besides this there were but few serial relations regarding particular properties, one of the most abundant sources of illusive theories and consequent deceptions; and, a much more promising nucleus, some sporadic instances of quantitative investigations as to the velocity of reactions and chemical equilibriums.

Such appeared to van't Hoff the most immediate and the most important goal—to fill up the great gap and try to fuse into one body of knowledge the few and scattered ideas which were possessed up to that time. It was with this intention that he quickly set himself to work, theoretically as well as experimentally. The first results of his researches were not put forth in simple detached monographs, but collected in a harmonious and comprehensive manner in the form of a book entitled " Etudes de dynamique chimique," which saw the

light in 1884. This book was filled with the spirit which henceforth was to inspire all the productions of van't Hoff.

The author attempted in it to apply, so far as possible, mathematical methods, and, above all, the principles of thermodynamics, to the study of chemical phenomena. The idea in itself was not new; 20 years before that Clausius had pointed out the possible application of these principles, especially of the second, but he had given no concrete examples of it. It is true there was also in existence the work of Willard Gibbs, but it was still lying like a colossal block of granite buried in the proceedings of an obscure American academy, ignored by scientists, certainly by all chemists. The only attempts of any importance at its application were those of Horstmann and Peslin and Moutier to the phenomena of dissociation.

The work of van't Hoff was much more considerable and systematic, and since the author, like a true chemist, carries abreast theoretical study and experimental verification, this work exercised a preponderant influence by making known to chemists the methods and principles of this new branch of science.

He studied principally the velocity of reactions, selecting the most varied types of changes, reducing to order their laws, and seeking to discover in what measure the methods of chemical kinetics are applicable to the determination of the order of the reactions. He invented the most ingenious methods to discover general laws when the latter are concealed by disturbing secondary reactions, which he eliminated in both experiment and calculation. He finally studied the variations which the velocity of reaction undergoes under the influence of the temperature.

From there he passes to the consideration of chemical equilibrium, viewed as the result of two inverse processes, and concerns himself first of all with homogeneous equilibriums in gases or solutions. He gives special attention to heterogeneous equilibriums and more especially to those which he calls condensed systems—that is, systems in which no bodies of variable composition, such as gases or solutions, intervene. He recognizes that in these cases, instead of having a continual displacement of the equilibrium, one has a transition temperature such that one of the systems is stable above this point, the other below. The transition temperature had been known for a long time in the polymorphic modifications of one and the same substance, as in those of rhombic and monoclinic sulphur; but the author generalizes this concept, and shows that one can extend it to the reciprocal transformation of chemical isomers, to the dehydration of hydrated salts, to the formation of decomposition of double salts, etc.

Discussing, then, the displacement of equilibrium which is produced by variations of temperature, he announces for the first time

the before-mentioned principle of mobile equilibrium, which he for-
mulates thus: "All equilibrium between two different states of matter
is displaced in consequence of the lowering of temperature toward
the system the formation of which develops heat." It is known
that this principle a little later was generalized by Le Chatelier,
who extended it not only to thermic variations, but to all altera-
tions of external and internal conditions of equilibrium (pressure,
electric state, concentration, etc.). He writes, therefore, thus:
" Every external action impresses on a body or on a system a change,
the direction of which is such that the resistance offered by the body
or by the system to the external action is increased." This principle
preserves its importance even beside the second principle of thermo-
dynamics, for although it authorizes only qualitative conclusions, it
may no less be used with success when it is a question of determining
the direction in which a certain process will take place, and especially
in the cases where it is not possible to bring the problem to the
mathematical form of the equation of Clapeyron or to other analo-
gous formulations of the second principle. It can at the same time,
thanks to its simple and general form, be easily remembered, since it
implies the idea of a sort of faculty of accommodation to exterior
actions inherent in matter.

Van't Hoff announced this principle, as we have said before, only
for thermal variations, but to attempt, for this reason, to detract
from his merit, as certain authors do, appears to us profoundly un-
just, for not to mention his indisputable priority, one must not forget
that the case treated by him is much the most important for chem-
istry. He succeeds thus in settling a question which had been engag-
ing chemists for a long time, since the problem concerning the direc-
tion toward which a recreation moves is, it will be admitted, of
fundamental importance.

It is known that Thomsen had, several years before, announced a
rule on which Berthelot wanted later to confer the dignity of a natu-
ral law—the principle of maximum work, according to which, of
all possible reactions, those might be produced spontaneously and
without intervention of foreign energies, the production of which
is accompanied by the greatest development of heat.

Now this rule, which is verified in practice for most of the ordi-
nary reactions of chemistry, is found at fault in different well-stud-
ied cases of chemical reactions strictly speaking and in entire series
of processes, like the reversible processes. While Thomsen recog-
nized the empirical character of his rule, Berthelot sought on the con-
trary to save his principle by the aid of a series of ingenious reason-
ings based on the ambiguity which is attached to the use of vague
expressions, such as " to be produced spontaneously " and " without
the intervention of external energy." But it was labor lost, so that

Duhem pitilessly remarked, one must in order to save this principle admit also, to the ranks of external energy, the heat absorbed in endothermic processes. The principle in question would amount, then, to the following statement: "Every process which does not absorb heat develops it"; that is, in order to remain true, it must "vanish into a ridiculous tautology."

Now, the principle of van't Hoff gives us the key to these contradictions; since a lowering of temperature favors the processes whose accomplishment is accompanied by a development of heat, it is the exothermic reactions which must be produced by preference at the low temperatures. And as the ordinary conditions of temperature of our surroundings and of common chemical operations represent zones sufficiently low in the complete scale of possible temperatures, it is natural that the rule of Thomsen should be verified in them, with a first approximation. Berthelot's principle would become rigorously true only at absolute zero. But to the high temperatures correspond principally the endothermic processes, and chemists living at a temperature of 3,000 degrees would sooner formulate a principle of minimum work * * *.

From this time on the work of van't Hoff is divided into two branches. While, following, as he will of course do, in addition, all the rest of his life the experimental research of heterogeneous equilibriums, and particularly of condensed systems, he devotes the best of his activity in the field of theory to the study of another fundamental problem—the theory of dilute solutions and the investigation of the molecular state of dissolved substances.

The theory of solutions, in its general lines at least, is now so well known that it would be superfluous to examine it here, but it may be interesting to consider its genesis. It would not be difficult to follow its course through the work of our scientist; but he has himself taken pains to make a clear exposition of it in a discourse delivered before the Chemical Society of Berlin in 1890: "Wie die Theorie der Lösungen entstand." One must seek its origin in the "Etudes" above referred to. He tries to find out the affinity which keeps water in solutions and in hydrated salts, and as Mitscherlich had previously done, he thought of founding a measure of it in the diminution of the vapor tension of these systems as compared with pure water; but the absolute value of these differences seems to him too slight in comparison with the strength which he felt even the smallest chemical forces shall have. He then asks himself if this attraction of water can not be measured in a more direct manner. With this question on his lips, as he himself relates, he comes out of the laboratory one day and meets his colleague de Vries. The latter, who was then busy with osmotic experiments, puts him in touch with the classic researches of Pfeffer on the direct measurement of osmotic pressure. And there

was found the link which he needed. He considers first the process of distillation of water vapor, which goes from pure water toward a solution, owing to the lesser tensions of the latter; he then examines the passage of water which goes through semipermeable membranes from the pure solvent toward a solution, owing to osmotic pressure; comparing the two phenomena with each other, he recognizes their parallelism.

But that is not enough. He had applied to equilibrium in gases one of his equations which is at bottom only the result of a combination of Clapeyron's equation and the law of the gaseous state, and wished to find out if this equation was equally applicable to solutions. He observes now that by means of semipermeable walls, and by substituting osmotic pressure for gaseous, it is possible for him to reproduce for solutions the cycles and the reversible modifications which have led him to deduce the equation for gases.

There results the necessary consequence that the laws of gases must also hold for osmotic pressure. He verifies the existing data and finds that the laws of Boyle and Gay-Lussac are in fact confirmed by the measurements of Pfeffer, and that consequently the principle of Avagadro must be applicable. Isotonic solutions must be equimolecular. And since the law of the gaseous state is applicable to solution, he calculates, according to the measurements of Pfeffer, the value of the constant R, and to his great surprise finds that the numerical value of this is with great approximation equal to that obtained for gases; the gaseous pressure and osmotic pressure exercised by a given quantity of dilute substance under a definite volume are equal.

From this moment the understanding is complete; the analogy between the gaseous state and that of dilute solutions is established. Van't Hoff is not slow in making clear the relations which connect the osmotic pressure with the diminution of tension of vapor, with the elevation of the boiling point and the lowering of the freezing point of solutions. Thus, he includes in the law set forth above the empirical rules already worked out by Raoult. It is thus that the direct measurement of osmotic pressure and indirect measurement, such as tensimetric, ebullioscopic, and cryoscopic determinations, which are much more exact and easier to carry out, lead to a determination of the molecular size of the substances dissolved. Our knowledge of the molecular state of bodies, limited at first to substances obtainable in gaseous form, is thus found extended to all soluble substances. What a revolution this extension produced in all domains of chemistry and allied sciences is so well known that it need not be dwelt upon.

This theory was set forth for the first time in its entirety in three memoirs presented simultaneously on October 14, 1885, to the Royal

Academy of Sciences of Stockholm and published in the proceedings of that academy the following year (1886). In these memoirs there is a rather notable limitation, namely, that all the aqueous solutions of salts, acids, and strong bases are exceptions, in the sense that they give too strong osmotic pressures. So van't Hoff was obliged to introduce into the equations which deal with them a coefficient i greater than (figure) *1.* This apparent exception was soon explained by a young Swedish physicist, Svante Arrhenius, who, three years before, had studied with great success the electric conductivity of solutions; since the anomaly of which we first spoke is manifested in solutions which possess electrolytic conductivity and since coeteris paribus it is the more pronounced the greater this conductivity, he supposes that the electrolytes are, at the moment of solution, largely separated into their ions.

It is thus that there originated the theory of electrolytic dissociation, which was inseparably connected from the first with that of solutions, the struggles and triumphs of which it shared.

Opposition could not be slow in developing. In fact the storm of astonished indignation which soon after broke out in almost the entire chemical world, was directed less against the theory of van't Hoff than against that of Arrhenius, which seemed to be attempting to overturn the most deep-rooted ideas; but objections to the first were not lacking, especially in England. While the greater number of French scientists shut themselves up in an opposition based on almost disdainful indifference, a group of chemists and of English physicists, with Pickering, Armstrong, and Fitzgerald at their head, partisans of the theory of hydrates, opened a real campaign against the new ideas. Better inspired, however, they did not seek to avoid discussion, but brought about a veritable war of words.

Few public discussions will remain as memorable and as interesting in the history of science as that which took place in 1890 at the meetings of the British Association at Leeds when the three greatest representatives of the new movement, van't Hoff, Arrhenius, and Ostwald, took part by express invitation.

These are the terms in which Ostwald speaks of this tournament:

I do not think I am wronging our hosts in supposing that the invitation had been given first of all with the friendly intention of persuading us that we were in error and of sending us back home again after a good lesson. And during the first days our adversaries alone held the floor, so that one might have thought up to a certain point that we were already scientifically dead. But when, after long and lively personal discussions, the representatives of the modern ideas finally had a chance to speak, even at the public sessions, the appearance of things was not slow in changing, and we were able to separate from our hosts in amiable fashion and not without triumph.

The ideas of our champions met a more cordial reception from Sir Oliver Lodge; and in the English field itself they found an influen-

tial ally in the person of Sir William Ramsay, their contemporary, who was already known through important studies, though he had not yet given all he was to give in publications, which since have made his name so universally famous.

From this moment the success of the new school was rapid and triumphant, the opposition which from all sides had been made against it was soon almost completely appeased; to be sure it did not entirely disappear, but it was only whispered, rather than expressed openly and supported by definite arguments.

The new theories were soon introduced even into elementary treatises, and now they have penetrated and transformed all branches of chemistry.

Discussions on the theories of van't Hoff have, however, been again renewed during recent years, both from theoretic and experimental points of view. An American physical chemist, Kahlenberg, after having carried out some measurements of osmotic pressure, claims to have arrived at the conclusion that the theory of van't Hoff is insupportable. But so radical a conclusion is little in accord with the modest experimental data on which it is based, data which, besides, have been contradicted by other writers, among them Cohen, one of the first pupils of van't Hoff. Another American, Morse, has shown in a series of much more exact and thorough experimental works that osmotic pressure follows the laws of van't Hoff up to a quite high degree of concentration. Scarpa has confirmed the fact that its variations with temperature follow the law of Gay-Lussac.

Other chemists and physicists who have not thoroughly studied the work of the master or who are acquainted with it only at second hand have attempted to criticize the ideas of van't Hoff concerning the mechanism of osmotic pressure. But that is like fighting windmills. It is true that van't Hoff has sometimes made allusion to a kinetic conception of solutions the parallelism of which with gases he had shown; but although he has had recourse to this conception in didactic exposition, he never used it to deduce his laws. Indeed, he has always brought out the fact that the mechanism of osmotic pressure and the manner of action of the semipermeable wall have no influence on the deduction and the development of the theory.

The truth is that the theory of dilute solutions (many forget this adjective on which van't Hoff had always laid stress) represents a limit law, like many other great natural laws, the value of which no one has ever, on that account, denied. The truth is, also, that the perfect semipermeable membrane is an ideal object impossible to attain and even now extremely difficult to approach.

But even if this membrane were a pure abstraction the theory of it would be none the less true, since all the laws of evaporation,

ebullition, and freezing of solutions—laws which are the necessary consequence of this theory—have been and still are to-day verified with the necessary accuracy. The thousands and thousands of ebulliscopic and, above all, cryoscopic determinations which have been and are daily being made in laboratories represent so many confirmations and place the theory on so solid a foundation, that no critic, however keen he may be, will be able to shake it.

It can not be denied that our ideas on the nature of solutions—of concentrated solutions in particular—and on the state of the dissolved substances have taken a new direction in the last few years and are tending to-day to return to a theory of hydrates or, in general, of solvates; that is, to admit the existence of combination of the molecules of the solvent with the molecules of the dissolved ions. But there is nothing in that which would conflict with the theory of van't Hoff; indeed, it is strong partisans of the latter who have inaugurated the new movement.

In this respect, again, the theory of van't Hoff is a limit theory; it corresponds to the purely physical conception of the solution in which the solvent has no other function than that of diluting, of separating from one another, the molecules of the substance dissolved; reality differs more or less from this scheme. The deviations have an insignificant effect only in the case of very dilute solutions and of especially indifferent solvents; in default of these circumstances the deviations cease to be negligible.

It often happens in the history of science that at a certain time two theories seem absolutely opposed to each other; one of them emerges from the struggle victorious. In the course of time, however, it is perceived that the contradiction was not by any means as necessary as had been believed at first, but that each of the two theories represented an extreme and too simple solution of the problem, and that the vanquished theory itself contained germs of truth, susceptible of development and adaptation.

As Walden remarked, one might have believed at Leeds 20 years ago that a chemical theory of hydrates was irreconcilably opposed to a physical theory of solutions; to-day Pickering can have the satisfaction of seeing rejuvenated his idea of combinations with the solvent; but far from appearing as a negation, this idea appears rather as a useful extension of the views of van't Hoff. The credit for having propagated this new movement belongs to Ciamician, who, as early as 1891, proposed admitting the formation of such solvates to explain electrolytic dissociation.

Permit me finally to draw your attention to the influence that the most recent study on the Brownian movement and on the nature of colloids has exercised on the questions that we are discussing. These brilliant researches have established the continuous passage

of coarse dispersions into true solutions in the strictest sense, and have given for the first time a plausible demonstration of the real existence of molecules, and thence of the kinetic nature of gaseous and osmotic pressures.

But let us return to our subject. In 1890 van't Hoff published a very interesting extension of his theory. He showed that it can be applied equally to the solid homogeneous mixtures of the nature of isomorphous mixed crystals, and founded thus the theory of solid solutions to the development of which the writer can congratulate himself on having contributed.

In the further development of the theory of solutions by experimental studies, van't Hoff took no more part, confining himself to making it public with the aid of recapitulations and explanatory articles and of conferences. He did not, however, abandon experimental work, which he followed with untiring assiduity, though he reserved this side of his activity for the other group of questions treated in his "Etudes de dynamique chimique," for heterogeneous equilibriums and condensed systems.

This domain had already been treated, particularly as to the phenomena of dissociation, by a brilliant French school which began with St. Claire Deville and ended with Le Chatelier, and another Dutch school, headed by Bakhuis Roozeboom, starting with only slightly different ideas, began to work in the same direction.

Van't Hoff and his pupils busied themselves first of all with the conditions of formation and of decomposition of double salts in aqueous solutions by devoting their attention on the one hand to compounds such as Astrakanite and Carnallite, which are minerals found in nature, and on the other hand to the racemates, thus again studying stereochemical questions. The results have been collected in a little book entitled "Vorlesungen über Bildung und Spaltung der Doppelsalze," published in 1897, one of the least known books of our scientist, because of the nature of the subject, which, although of great importance, is of such an abstruse character that it can be treated only in a somewhat dry fashion.

This group of works covers the decade from 1886 to 1895, the second period of van't Hoff's stay in Amsterdam.

We now come to the Berlin period of his activity, devoted entirely to the application of principles and methods previously discovered, to the investigation of the conditions of formation of oceanic deposits and particularly of the famous deposits of Stassfurt. In this work, which was the first, and remains the greatest, attempt to apply physical chemistry to the problems of geology and to transform the latter, so far as possible, into an experimental science. he had Wilhelm Meyerhoffer as a constant collaborator for 10 years, until his untimely death, in 1906, at the early age of 42 years.

He was no ordinary collaborator; when, in 1896, he became associated with the master in the founding of the little private laboratory of Hollandstrasse he had already written, among others, a little book on the phase rule, which is still one of the best on this question, and had already carried out very important experimental work on the affinities of reciprocal pairs of salts, a subject which for problems that he was treating was of the greatest importance. In theoretic questions he was an absolutely independent and original thinker and not always in accord with the master.

* * * The mother idea of the common work belongs in great part to Meyerhoffer, as van't Hoff has always openly admitted. In his work on reciprocal salt pairs, Meyerhoffer had expressed in 1895 the opinion that "the formation of the saline deposits of Stassfurt, Wielicza, and other places, inasmuch as they are of marine origin, can not be explained in a satisfactory manner until one has submitted to a systematic research the solubility and the equilibric connections which occur among salts which are found in the water of the sea."

Further, in 1889, in a rectoral discourse at the University of Leyden, van Bemmelen made allusion to the opportunity of applying the methods in question to the solution of geologic problems. Can we say on that account that van't Hoff brought to this question no original contribution? Nothing would be more absurd. In 1887, before the work of Meyerhoffer and the allusion of van Bemmelen, he had established the conditions of formation of different salts existing in the layers of oceanic origin, such as the astrakanite, the leonite, and the schönite, and the method of research which has been used to clear up the question is no other than that which he introduced. Meyerhoffer himself was inspired by his earlier works and had carried out in his laboratory his inaugural work.

The investigation lasted 10 years, and is set forth in 51 separate papers, which were all published between 1897 and 1906 in the Proceedings of the Academy of Sciences at Berlin. We should be carried too far if we tried to give an idea of them, even a brief one. It is known that the deposits at Stassfurt, which are considered as having been produced by the evaporation of an inland sea, are composed essentially of chlorides, sulphates, and borates of sodium, potassium, magnesium, and calcium, and of all their possible double salts. It was a question of determining the order in which they were deposited, the possible interrelations of minerals (what is called paragenesis), the limits of temperature and of concentration in which the different separations and the various types of paragenesis could take place. In order to solve so complicated a problem, they worked by preference, in determining the solubility at different temperatures, first on pairs of salts, then on all the possible complex systems; to

establish the different temperatures of transformation they used ordinary tensimetric and dilatometric methods.

The problem may be considered to-day completely solved, at least so far as its theoretic side is concerned. Moreover, the results agree on almost all points with those obtained by mineralogists and those in practical work; some of the new minerals, one of which bears the name of vanthoffite, at first unknown and prepared synthetically, have been since found in nature as a result of the suggestions given. The importance of these studies, even from the practical point of view, has been recognized by practical men and by the German government. A committee was in fact established, in 1908, charged with making a detailed study of the deposits of Stassfurt, with reference to their application, but based principally on the work of van't Hoff. * * *

We have come now to the end of this brief review of the life of the master and of the different phases of his scientific work. But our purpose would not be fully attained if we did not turn back for a resurvey of the entire field to see his figure as a man and a scientist as it was in reality.

As I have already said, he reproduced in his features the Dutch type, he had a height slightly above the medium, and in his manner of dressing and of speaking, as well as in familiar conversation, he appeared as he was—modest; only the gentle but keen and penetrating eye betrayed at times the exceptional man that stood before one.

As a man he was not one of those who weaken the splendor of their genius by crudities and extravagances of character; his real goodness, his serene gentleness, his modesty, even reaching almost to ingenuousness, have brought him as many affectionate friends as his work procured him admirers.

He had as many and as high academic and scientific honors as a man could wish; of ambitions of another kind he did not possess the slightest trace; his life ran tranquilly in the bosom of his family, consisting of his wife, whom he had married while she was very young, two daughters, and two sons. He was a complete stranger to the spirit of domination and intrigue, and for this reason he never had to suffer any of those jealousies and envies so frequent even in the academic world. No superiority has ever been recognized so tacitly and unresistingly as his, which he never made any one feel, whoever it was.

He was extremely reserved when it was a question of expressing opinions on things, and particularly on men; and it was only after a long period of intimacy that one could hear him pronounce explicit judgments, especially if they were not favorable.

His general culture was certainly very wide, particularly in the scientific domain. He appreciated arts and letters and attached to them great importance, even when taking the point of view of pure science; that is what his inaugural address (as we have already mentioned) teaches us, about the imagination in the exact sciences; we learn in it also that one of his favorite subjects for reading was the lives of great scientists, which he would devour in great quantities until he could cite more than 200 of them.

As to his philosophic and religious ideas, we know that as a young man he was admirer and partisan of the positive philosophy of Aug. Comte; but his opinions have never been, so far as I know, the object of exterior manifestation; so much the more from several expressions in a necrology of Roozeboom, in which he speaks, though in respectful terms, of the religious fanaticism of the latter and of the desire which he expressed of being cremated; so much the more, I say, can one conclude from these expresions that he remained, to the end of his life, faithful to his first ideas on these questions.

He had not the qualities of a brilliant and popular orator and, a stranger to every sort of dilettanteism, he had never yielded to the desire to appear attractive; but his lectures of a general and recapitulatory character are read none the less willingly and with profit because of the clearness and richness of their ideas, although they are not always easy reading. In some necrologies—for example, in those of Meyerhoffer and Roozeboom—he has given free course to sentiment, and succeeds often in finding efficacious and moving expressions.

Just as he was not an orator for large audiences, so he was not made for elementary teaching; he said so himself, in a lecture, and it was to rid himself of this obligation, for him a sacrifice, that he decided to accept the situation which had been made for him in Berlin. He gave here regularly a single course of one hour a week on selected branches of physical chemistry, and from this course, which was delivered to limited audiences, came his book, "Lessons on theoretical and physical chemistry," which had great success, thanks to the original and completely personal manner in which the subject was developed.

If the position of professor in the broad sense of the word was often burdensome to him, he was always gratified with his rôle of master to the young students, already mature, who worked with him in his researches.

As he never had large laboratories, he was never surrounded by very many pupils; but some of them have succeeded in making for themselves prominent places in science as well as in teaching. We have already spoken above of the interesting personality of the

lamented Meyerhoffer. Among others one can not pass in silence Ernest Cohen, formerly his assistant in Amsterdam and to-day professor at Utrecht, the most faithful and best authorized interpreter of the thought of the master; from his loving activity we expect the work which shall make the figure of the latter live again in all its details before us.[1] Heinrich Goldschmidt and G. Bredig, now professors at Christiania and at Zurich, each spent several years in his laboratory in Amsterdam.

The writer of these lines can not help referring, in thought, toward that laboratory at Wilmersdorf, near Berlin, in which he had the pleasure of working during the years 1900–1901. It was a little laboratory located in a rented house conveniently furnished for the researches which were made in it (on the Stassfurt salts), but not for anything else; beside van't Hoff, Meyerhoffer, and an appointed assistant there was not room for more than five or six students. There never was, I believe, a more international and polyglot laboratory; one may say that, except the French, all nationalities have been there. The meetings with the master were frequent and familiarly cordial. Certainly the day of the announcement of his death none of us who had been permitted there could help thinking, with a melancholy not without tenderness, of the days which passed by in the peaceful work at Wilmersdorf.

But beyond these details it may be interesting to inquire into his manner of procedure in intellectual work and his attitude in regard to some of the great questions which agitate and divide the scientific world.

His mind was first of all synthetic and coordinative: his work, by choice, always consisted in studying a large number of facts in order to make out their reciprocal relations and express them in general laws. Certainly in him, as in the case with most inventive minds, the result was already present when the demonstration was not yet finished—another proof of the fact that progress, based on a flight of the imagination rather than on a series of successive and maturely considered steps, has an essential part in the development of science. That was the favorite thesis of van't Hoff.

But he was perfectly aware that the success of such a flight does not remove from the exact scientist the obligation of returning and uniting, by a passageway offering every security, the point attained with the shore which had served as a point of departure.

And, indeed, one of the characteristics which strike us in his work is that when he announced a theory he announced it already complete. Let us consider his three principal works—stereochemistry, the studies in chemical dynamics, and the theory of solutions; each

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[1] This expectation has meantime been fulfilled : see " Jacobus Henricus van't Hoff, Sein Leben und Wirken, by Ernst Cohen, xv, 638 pp. Leipzig, 1912.

of the three fundamental publications which bear on these contained all the essential parts of the respective theory not only in germ but sufficiently developed and demonstrated.

This creator of theories, this man who gave science so many new ideas, was nevertheless a stranger to all metaphysics, to every exaggeration; he was not one of those who, into whatever domain they enter, wish at any price to create a general system which embraces all the universe, which shall comprise all important and unimportant facts, existing and not existing. Though a generalizing and synthetic mind, he was never abstract nor schematic. We see this also in the lectures in which the theories are almost always set forth, not in an abstract fashion, but resting upon concrete examples.

This tendency of his mind explains his attitude with regard to the theory of phases, and this point is one of the most curious in the scientific life of van't Hoff. It is known that the phase rule is contained in the great work of Willard Gibbs, published between 1874 and 1878 in the Proceedings of the Connecticut Academy; but it remained unknown for about 10 years, until van der Waals mentioned its importance in a private conversation with Bakhuis Roozeboom, who had already commenced his researches on heterogeneous equilibrium. Roozeboom for the first time adopted the phase rule for the classification of heterogeneous equilibriums in 1887, three years after the publication of "Etudes de dynamique chimique." Now, in the part relating to heterogeneous equilibriums, to condensed systems, to double salts, etc., the studies of van't Hoff have already penetrated from one end to the other of the understanding of the theory of phases; they are the theory of phases in action, and he lacks only the definite schemes, for Gibb's phase rule is, at bottom, nothing else.

It is psychologically comprehensible that van't Hoff had conceived a certain aversion for this theory, an aversion which he never gave up; he spoke of it reluctantly, and never used it in his treatises. It was only in 1902 that he decided to present to the Chemical Society of Berlin a recapitulatory address on this subject, an address in which, besides a clear and objective statement of the theory and of its applications, are found these phrases, which translate his thought or rather his sentiment: "It is regrettable that, whatever may be the importance of the phase rule, the appreciation of its value has been somewhat exaggerated. Many things are attributed to it which are not due to its application. The great importance of the phase rule rests less in the value which it may have as a guide in research than in the pedagogic value which it presents whenever it is a question of treating and classifying the phenomena of equilibrium."

Now, this does not seem to me quite exact, and I may say that that is the only point in which I find that van't Hoff is a little lacking in justice and yields unconsciously to a weakness. That the theory of

Gibbs has given rise to some exaggerations, that one may even in the most complicated labyrinth of heterogeneous equilibrium discover the right way without having recourse to the theory of phases, that all the individual cases involved can be solved without one's being obliged to state the law—all that is indisputable, and van't Hoff has furnished a practical demonstration of it; but it is no less indisputable that there is a great utility in the fact that the particular types and the rules relating to them may be united into one body without one's being obliged to find them again each time, the scheme being capable of great usefulness not only for classification, but because it furnishes a convenient guiding thread in research, especially to those who have not the breadth of mind of a van't Hoff.

Van't Hoff was a faithful partisan of the atomic and molecular theory. One could expect nothing else from the founder of stereochemistry. Friend and companion of Ostwald in the struggles for the modern physiochemical theories, he separated from him when the latter declared war on the atomistic theory in the name of the energetic, not only by doubting the real existence of atoms and molecules, but by denying the possibility of ever demonstrating this existence, and disputing even the advantage of the use of the atomic theory as an instrument of work. When the campaign of Ostwald, which a prompt defeat awaited, was in full swing, van't Hoff gave, in 1906, in Vienna, a lecture in which, without departing from his calm and serene tone, he put people on guard against the dangers of this movement and affirmed once more his conviction that the atomic theory was still destined to render great service to science.

Of the two courses which physical chemistry can pursue he followed the chemical one. As a chemist he was always interested in the substances themselves, the physical properties interesting him only as characteristics of the substances, and the general laws themselves, as well as the physical and mathematical methods, interesting him only as more perfect means toward the investigation of their nature—a means permitting one to give of the infinite variety of the latter a quantitative and more exact expression than could be obtained with the vague concepts and inexact methods of traditional chemistry. On the other hand, what interests the physical chemists of the other wing, as well as the pure physicists, is above all, the properties in themselves, the substances appearing to them only as the inevitable bearers of these properties.

In any case it is certainly no injustice to even the most famous physicochemists of his generation to say that he was head and shoulders above them. If one wants to find men whose worth is comparable to his one must go further back to the heroic times when

the differentiation between chemists and physicists was not yet marked; and to the mind are presented names like those of Bunsen, Faraday, Gay-Lussac. But of what use are these comparisons? It is certain that he belongs to the stars of science of first magnitude, to those whose light does not grow pale.

Of the four great subjects which he has treated each one would be sufficient for the glory of a great chemist; two of them (stereo-chemistry and the theory of solutions) are among the greatest bodies of theory of universal science, and one alone would be enough to assure its founder a place among the greatest. Thus his glory instead of becoming less can only increase, since it depends not on the exceptional exterior quantities of the man but on the greatness of the work accomplished.

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